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HEAD-UP DISPLAY WARNING REQUIREMENTS RESEARCH

David J. Sheehan

United Aircraft Corporation

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HEAD-UP DISPLAY WARNING REQUIREMENTS RESEARCH

FINAL REPORT

David J. Sheehan

AUGUST 1972

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13. ABSTRACT

A study of head-up display requirements was conducted to determine aircraft and mission warning information to be included in the head-up display and how this information should best be presented to the pilot. Using the A-7E as a representative aircraft, a review was made of discrete warning, caution, and advisory information available from various aircraft and mission systems. Candidate warning messages were analyzed for pilot response in each general mission phase. Current practice in aircraft warning systems was reviewed. An extensive survey was conducted of pilot experience with the A-7E head-up display. Display format requirements were identified and developed using human engineering analysis, pilot opinion, and laboratory experimentation. Laboratory investigations involved flashing vs steady symbols, warning message size and shape, enhancement by changing color or brightness, and location of warnings in the HUD visual field. Resulting HUD warnings and display format requirements are considered applicable to other Navy aircraft such as the F-14. Unique equipment, programs, and experiments were developed to validate the head-up display warning requirements. The aparatus included an analog simulation of the A-7E and a programmable head-up display and warning system. HUD warning information, and display requirements are recommended. Further research is recommended to optimize HUD symbols for night operations; to develop requirements and standards for integrating tactile and auditory displays; and to evaluate, using the programmable simulation, new HUD symbols for thread avoidance, low level navigation, and recovery from unusual attitudes.

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SECTION 1
INTRODUCTION

The head-up display (HUD) is a relatively new type of cockpit display used for flight control and weapon delivery in high performance military aircraft. Collimated, virtual images are projected into the pilot's forward visual field as he looks through the windshield. This allows the pilot to continuously view the real world - without shifting his visual attention from the real world to the instrument panel during critical maneuvers. Eliminating shifts in visual attention also eliminates attendant changes in brightness accommodation and in refocussing from large distances to the near cockpit panel.

With a head-up display, the pilots' visual attention is directed away from the instrument panel for considerable periods of time. Therefore, for maximum safety and pilot confidence, it may be desirable to display certain instrument panel warning signals on the HUD. This study was performed to determine (1) the warning information to be included in the head-up display and (2) how this information should best be presented.

The representative aircraft was the A-7E, and a review was made of the discrete information available on malfunctions and degraded levels of performance in various aircraft and mission systems. Candidate messages were analyzed for pilot response in each mission phase.

An extensive survey was then conducted of Navy pilots with operational experience using the A-7E head-up display. Semistructured interviews were conducted at Pax River and NAS, Cecil Field. A formal questionnaire was developed and completed by 87 pilots at both NAS, Cecil Field and NAS, Lemoore (refer to Appendix B).

Display format requirements were developed by analysis, pilot opinion, and direct laboratory experimentation. Laboratory investigations involved flashing versus steady symbols; warning message size and shape; enhancement by color and brightness; and location of images in the visual field of the HUD. Resultant HUD warnings and display format requirements are considered applicable to a number of other Navy aircraft, such as the F-14 and S-3 as well as to the A-7E.

Equipment and experiments have been developed for validating the head-up display warning system. The apparatus includes an analog simulation of the A-7E aircraft and a programmable head-up display and warning system.

SECTION 2
ANALYSIS

2.1 Present Practice

The present military aircraft warning system consists of a general visual alerting signal (MASTER CAUTION) and centrally located worded messages (CAUTION PANEL). A separate warning is usually added for ENGINE FIRE. When a warning occurs, the MASTER alerting signal and the specific message light are illuminated simultaneously. Depending upon the pilot's system of priorities, he redirects his attention to read the specific message and then acknowledges the warning by depressing the master caution (MC) reset. This lighted pushbutton switch is usually located at the top of the panel for maximum noticeability. It is possible that the pilot may elect to extinguish the alerting signal first before reading the message. Known false or intermittent warnings can be disabled on the caution panel on an individual message basis, but the summary alerting signal cannot.

The FIRE warning system illustrates the complexity that can exist in conventional warning systems. In multiple engine aircraft, a MASTER FIRE warning (press to reset) is provided. To determine the location of the fire, the pilot must refer to individual warnings associated with each engine or area in the vehicle. Sometimes more than one fire detection system is incorporated, viz. a continuous wire resistive element and an IR surveillance system. With multiple engines, an elaborate extinguishing system is often provided; this may require careful selection and preparation (arming) by the pilot. Both the detection and extinguishing systems may be provided with preflight and inflight test controls. This complex display-control subsystem usually requires a second or third man to operate it while the pilot continues to keep the vehicle airborne. As another example, enemy antiaircraft weapons pose a serious threat for tactical aircraft. A separate warning system is provided thus requiring interpretation and response time, which are just not available to a busy pilot in combat. The proliferation of warning/caution annunciators in their complex cockpit context is evident from an examination of Figures 2-1 and 2-2. Various auditory warnings are also included as part of the pilot's environment. Tactile warnings, such as pedal and stick shakers, are sometimes used.

In summary, there is a pressing need for warning system integration. Present HUD warning systems, moreover, which are summary in nature, may alert but do not convey specific information to the pilot. In a complex situation, where time is of the essence, the system should alert and inform simultaneously.

The A-7E HUD displays a master caution/warning symbol, consisting of six slanted bars in the lower part of the field of view. This is shown in Figure 2-3, together with a represent-

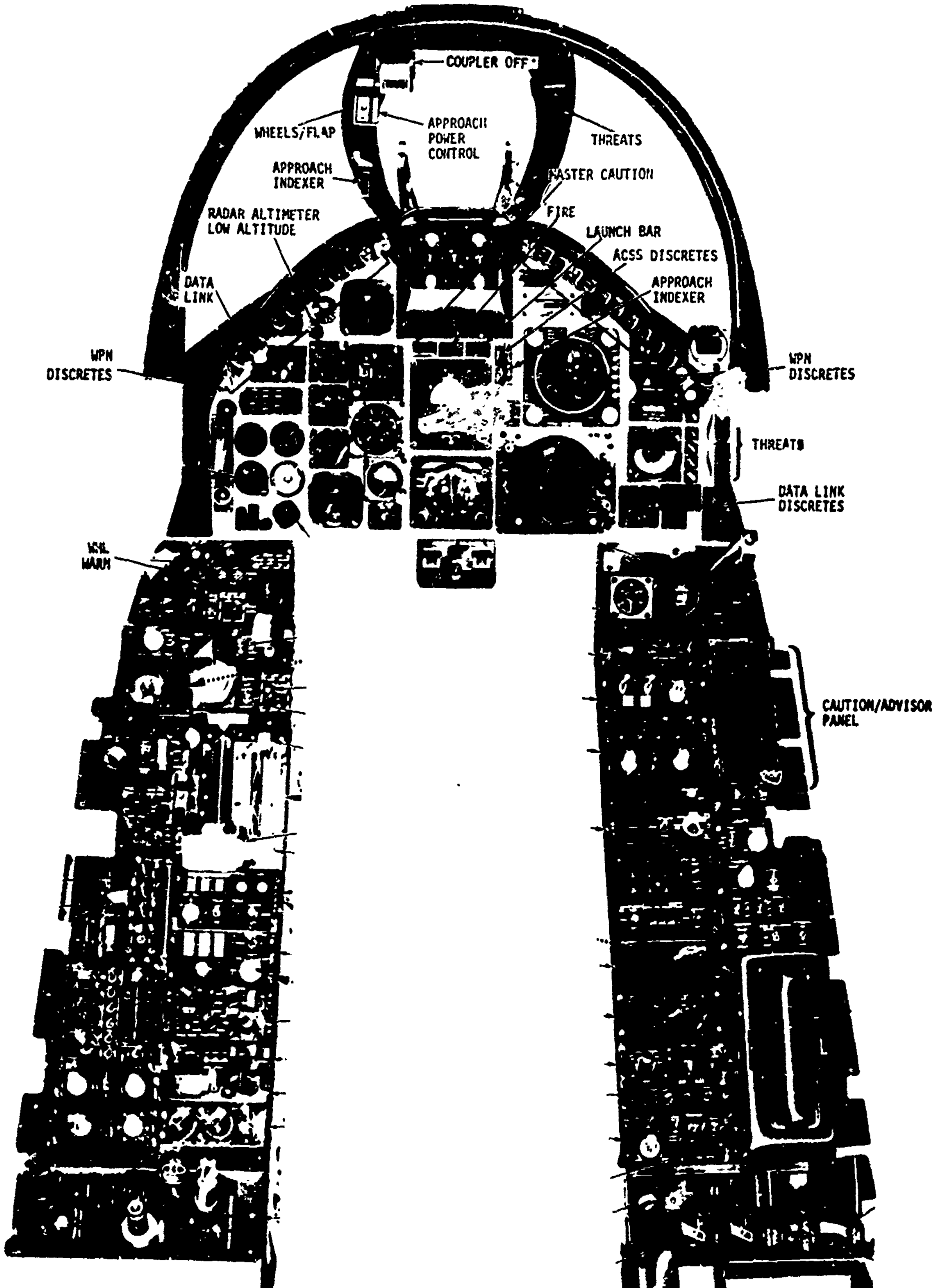


Figure 2-1. A-7E Cockpit Instrumentation

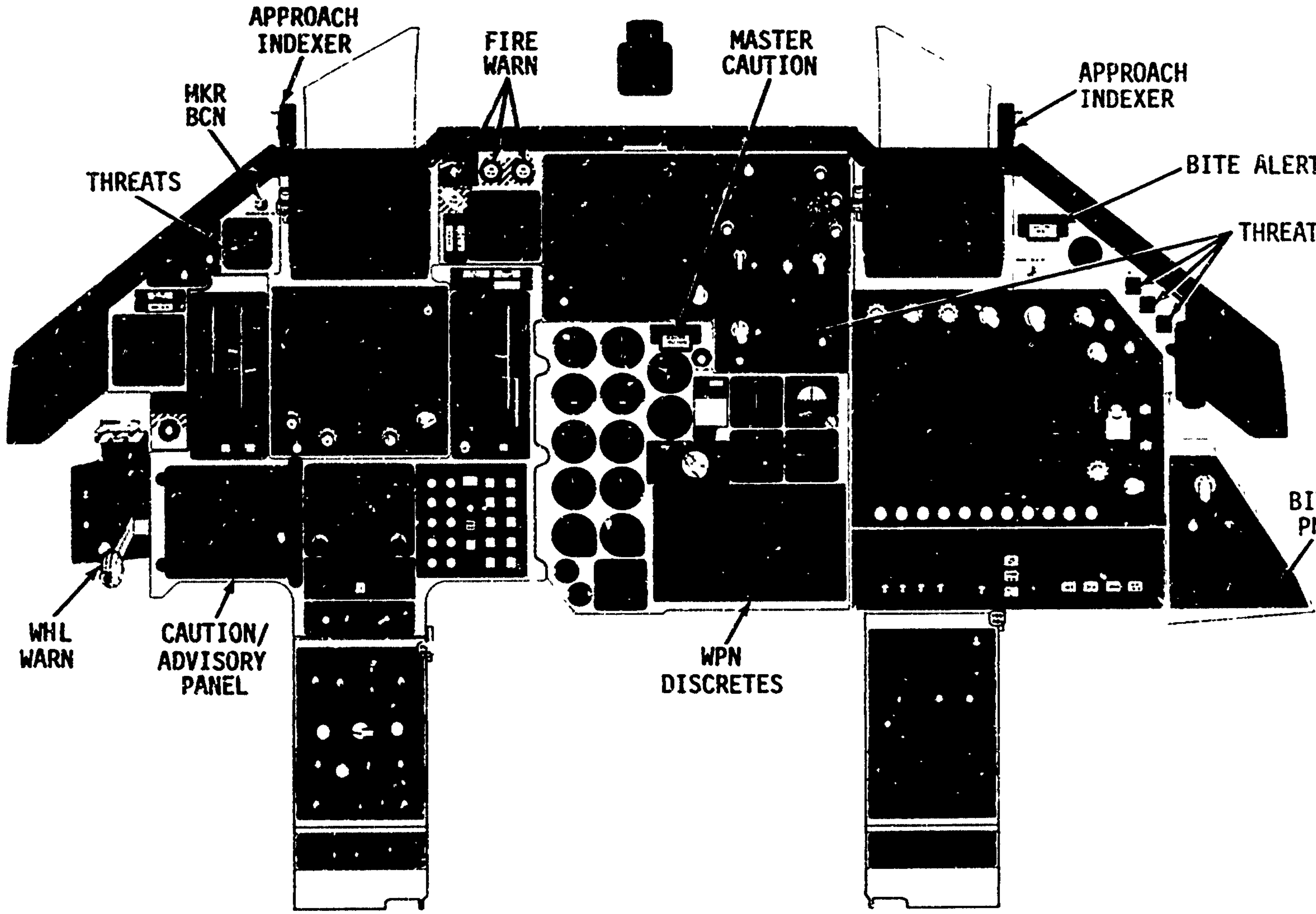


Figure 2-2. F-111D Cockpit Instrumentation

ative set of symbols. The F-111D presents separate WARN, FUEL, and CAUTION discretes, as shown in Figure 2-4.

Warning systems are governed by Mil Spec 8177. and Mil Standards 411D, 1472, 230, and 250. These documents, however, provide no criteria for warning conditions, nor do they consider the effect of warning system design on crew task loading.

2.2 Factors Influencing a New Design

There are numerous operational and human factors considerations that influence the design of a HUD warning system. The following paragraphs describe these considerations and include the additions and modifications obtained as a result of the initial pilot survey.

a. When the pilot is fully involved with aircraft control, his attention will likely be on the outside world through the HUD, e.g. carrier takeoff, low level reconnaisance/terrain following, refueling, weapons delivery, landing, etc. In such cases, summary warning signals will be attended to at the pilot's discretion. Generally, he will not scan his cockpit caution and warning lights until critical maneuvers are safely completed even though some critical warnings may warrant immediate attention. Such emergencies include engine flame out, fire, impending collision, imminent ECM threat, stall, loss of primary control, and lack of breathable air.

b. If summary warnings are used on the HUD, in those cases where the pilot cannot attend to them, he is distracted by the uncertainty of the exact condition.

c. If summary warnings are used on the HUD, the pilot must redirect his attention inside the cockpit to look for the individual message. The elapsed time to read the message and return to the original task will be on the order of 3 seconds. This time is required to redirect attention, shift the eyes, adapt to a new brightness level, refocus, read the message, return to the outside world, readapt to the outside brightness level, redirect attention, and refocus.

d. In some cases, a message will not affect the pilot's immediate tasks. In some cases, a message may provide no new information - the pilot is already aware of the situation. A warning under these circumstances is an undesirable distraction.

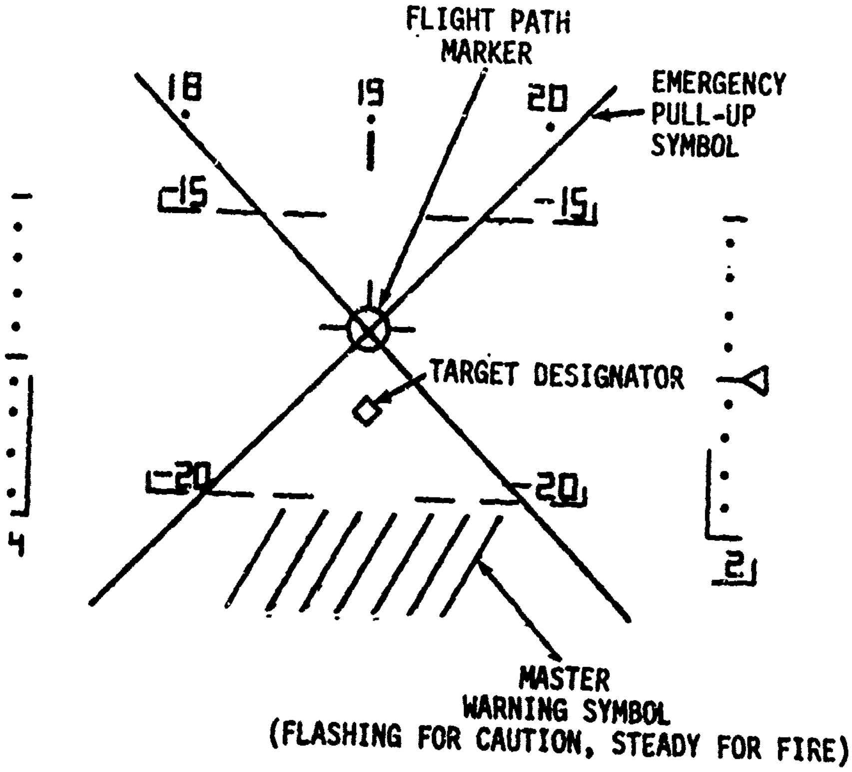


Figure 2-3. A-7E HUD Symbols With Warning

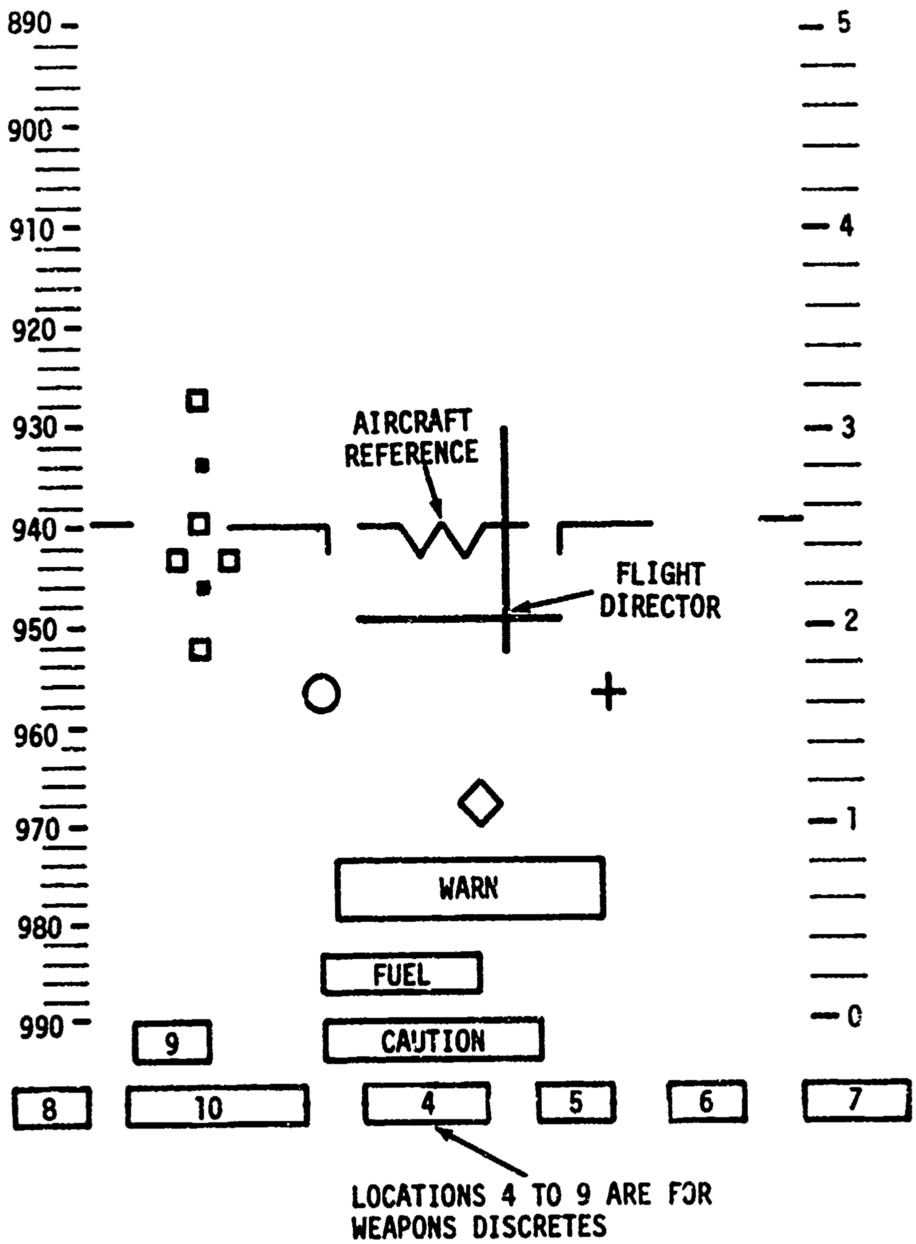


Figure 2-4. F-111D HUD Symbols

e. Warnings should not startle or annoy the pilot such that his safety is further jeopardized by his own inadvertant response.

f. Warnings displayed in cryptic form are apt to be misinterpreted, especially in periods of stress.

g. Often, the warning situation is obvious without resorting to cockpit instrumentation. Examples are major engine and electrical power loss, stall, and some control system failures.

h. The meaning and urgency of a given warning is directly related to the mission situation. The situations can only be completely identified by the pilot, if at all.

i. In some cases, the pilot's attention is neither in the cockpit nor through the HUD, e.g. low level reconnaisance, close formation, searching for another aircraft, etc. Under these circumstances, it is likely that all visual warnings on the HUD, near the HUD, and on the cockpit panel - will go unnoticed. These periods may be 30 seconds or more.

j. HUD illumination is usually turned down to prevent the HUD symbols from obstructing the view of the real world. This reduces the likelihood of seeing HUD warning signals.

k. HUD warnings cannot be displayed so close to the central field of view that they might interfere with a target or with more critical HUD symbols. Conversely, warnings cannot be displayed at such a peripheral angle that they might be missed.

l. The geometry of the cockpit, the size and shape of the individual pilot, and his preferred seat position may prevent visibility of either a HUD warning or the master caution and warning light.

m. Warning systems for military aircraft should be specified and designed as though there were only one man aboard, under the assumption that all but one man may be incapacitated.

n. Any new warning system should aid operational readiness. It should not impose additional preflight, in-flight, or post-flight tasks, except for a confidence check at the pilot's option. The warning system should be considered as an aid to preoperation checkout.

o. The threshold at which a warning is triggered is significant. This level must be low enough to provide adequate time to take corrective action, but must not be be so low that the pilot disregards the warning. This important design factor is a separable problem and has not been considered in this study. It does bear significantly on the overall design.

2.3 Technical Approach

The study began with an analysis to identify warning requirements as a function of mission phase. An initial HUD warning format was also developed, and requirements for human factors experiments were identified. This work was based on data from existing specifications, flight manuals, and research reports, with emphasis on the A-7E. The intermediate result was a tabulation of available warning signals and required pilot responses. This enabled an analysis of the feasability and urgency of adequate corrective action as a function of mission phase. The factors discussed in section 2.2 were applied at appropriate steps of the analysis.

The preceding tasks, coupled with a review of current warning system practice, led to the development of a pilot survey questionaire and a plan for subsequent laboratory testing - activities described in subsequent sections of this report.

SECTION 3
SURVEY OF PILOT EXPERIENCE

A study and analysis of available data served as the preparation for the survey of pilot experience and opinion. The purpose of the survey was threefold: (1) to obtain all possible data on current HUD and warning system usage, (2) to obtain pilot opinion on the present HUD and warning system, and (3) to obtain recommendations for improvements to the present HUD and warning system.

The survey was conducted in three stages: (1) informal interviews at NATC, (2) survey by means of questionnaire at NAS, Cecil Field, coupled with informal discussions, and (3) a survey by mail extended to pilots at NAS, Lemoore.

3.1 Interviews at NATC

A list of questions was prepared and discussed with ONR prior to the visits at NATC. Also, candidate signals were grouped by mission phase and placed in packs of 3x5 cards, one pack per phase. The phases were pretakeoff, takeoff, cruise, attack, and landing.

The intent was to have test pilots sort the cards into response categories for each mission phase. The response categories suggested were: less than 3 seconds, 3 to 15 seconds, and "check prior to next phase." This approach proved awkward; the pilots were unable to group the signals by response categories. The semistructured interviews accomplished the primary purpose of education, however, and provided the information to develop a formal questionnaire.

A summary discussion of the pilot comments at NATC is contained in the following paragraphs. An extended list of specific comments is contained in Appendix A. Six test pilots were interviewed at an average of one hour each. Discussions were limited to experience with the A-7E.

In summary, new HUDs should be more accurate in attitude (roll in particular), have slightly larger symbols, exhibit no jitter, and have a larger instantaneous field of view. Attitude and airspeed thermometers should be replaced with digital readouts. A g meter should be added for toss bombing. Bearing and range should be added to aid navigation. Symbols should be prevented from piling up as a function of wind drift. A simple display for recovery from unusual attitudes would be welcome.

There was general agreement that specific worded messages should be provided on the HUD for individual alerting signals.

One pilot suggested automatic cancelling of warning messages. The ability to silence individual warnings after initial alert is a general requirement that has been reduced to practice. Generally, automatic display of emergency procedures on the HUD was considered an overkill.

The pilots believed that further development of HUD symbols was necessary. They believed that the design of symbols shold be based more on assessment of actual performance and less on unfounded opinion.

There were several comments that, with the seat high (during attack, for example), the panel FIRE and CAUTION lights were not visible. This suggests the need for a well specified standard eye position, plus a means of telling the pilot when he is at or near that position.

3.2 Formal Surveys by Questionnaire

Surveys by questionnaire were conducted at NAS, Cecil Field and NAS, Lemoore, the latter by mail. Eighty-seven pilots were surveyed. These pilots had an average of 1573 hours of flight experience and an average of 283 hours with the A-7E HUD. Refer to Table 3-1.

A sample of the questionnaire is included as Appendix B of this report. Summary responses have been entered on the sample for Section I, General, and Section II, Mission Phases. These sections were intended to broaden the data base on HUD and warning system usage. Section III, Candidate Messages, served the basic purpose of identifying desired warning messages and their priority as a function of mission phase. Summaries of Section III are shown in Tables 3-2 and 3-3.

Comparison of Tables 3-2 and 3-3 shows good agreement between the two sets of responses. This indicates that the questionnaire is a stable survey instrument. In fact, the maximum number of messages (40) is identical with the maximum number of discrete voice messages in the AN/ASH-19 voice warning system for Army helicopters.

The primary conclusion from Tables 3-2 and 3-3 is that an extensive number of warning signals is needed, that they should trigger individual messages, and that the warnings and their priorities should be determined and changed as a function of mission phase. In a particular aircraft development, the manufacturers interact with the users in the complex evolutionary process of identifying and determining the priorities for warning signals. Significnat need for change may arise well into operational use. Thus, ease and speed of warning signal updates becomes attractive.

Table 3-1. Summary of Pilots Surveyed

SQDN NO	PILOTS REPORTING	TOTAL FLT HRS	AVERAGE FLIGHT EXPERIENCE (Hours)	TOTAL HRS A-7E HUD	AVERAGE HUD EXPERIENCE (Hours)
VA-174	14	27,150	7,939	1,470	105
VA-81	12	20,120	1,677	4,305	359
VA-83	10	12,740	1,274	2,655	266
VA-113	18	25,149	1,397	5,949	331
VA-27	13	22,130	1,702	4,370	336
VA-25	8	8,980	1,123	1,670	208
VA-97	12	20,560	1,713	4,240	353
SUMMARY	87	136,829	1,573	24,659	283

Table 3-2. Message and Priorities by Mission Phase (NAS Cecil Field)

TAKE OFF	CRUISE/NAV	ATTACK	LDG
1. FIRE	1. FIRE	1. FIRE	1. FIRE
2. ENG OIL	2. ENG OIL	2. HYD PRESS	2. WHL/FLP
3. PC1,2,3	3. HYD PRESS	3. ENG OIL	3. HYD PRESS
4. ENG HOT	4. FUEL LOW	4. PLATFORM	4. LAUNCH BAR
5. WHLS/FLP	5. FUEL PUMP	5. FUEL LOW	5. ADA OFF
6. PLATFORM	6. PLATFORM	6. CMPTR	6. PLATFORM
7. FUEL PUMP	7. OIL QUANTITY	7. AIR DATA CMPTR	7. ENG HOT
8. LAUNCH BAR	8. OXYGEN	8. ENG HOT	8. FUEL PUMP
9. CMPTR	9. ENG HOT	9. FUEL PUMP	9. FUEL REM(MIN)
10. OXYGEN	10. FUEL BOOST	10. LAUNCH ALERT	10. FUEL BOOST
11. RAD ALT OFF	11. CMPTR	11. FUEL BOOST	11. WPN ARMED
12. ANTI-SKID	12. PC 1,2,3 LOW	12. OIL QUANTITY	12. CMPTR
13. TILT	13. WING PRESS	13. ALTITUDE LOW	13. CPLR OFF
	14. ECM INOP	14. OXYGEN	14. APP PWR COMP
	15. ALTITUDE LOW	15. PULL UP	15. LDG CHK
	16. ADA OFF	16. ECM INOP	16. ENG OIL
	17. ECM REC	17. IN RANGE	17. TILT
	18. ECM RPT	18. WING PRESS	18. AFCS
	19. HUD HOT	19. WHL/FLP	
	20. RAIN REMOVE HOT	20. ROUNDS REMAINING	
		21. AAA	
		22. HUD HOT	
		23. WEAPONS SAFE	
		24. MAN FUEL CONTROL	
		25. RDY TO FIRE	
		26. RADAR FAIL	
		27. AIW	
		28. IN RANGE	
		29. MASTER ARM	
		30. SAM HI	
		31. SAM 3 (X)	
		32. SAM 2 (SRC)	
		33. AIW/AIDAY	
		34. SHI	
		35. SLO	
		36. ECM RPT	
		37. ECM REC	
		38. AI DAY	

Table 3-3. Message and Priorities by Mission Phase (NAS Lemoore)

TAKE OFF	CRUISE/NAV	ATTACK	LDG
1. FIRE	1. FIRE	1. FIRE	1. FIRE
2. LAUNCH BAR	2. TILT	2. HYD PRESS	2. WHL/FLP
3. PLATFORM	3. HYD PRESS	3. FUEL LOW	3. HYD PRESS
4. ENG HOT	4. ENG OIL	4. ENG OIL	4. AOA OFF
5. CMPTR	5. PLATFORM	5. LAUNCH ALERT	5. PLATFORM
6. HYD PRESS	6. OIL QUANTITY	6. WPNS SAFE	6. LAUNCH BAR
7. ENG OIL	7. FUEL PUMP	7. PLATFORM	7. FUEL REM (MIN)
8. WHL/FLP	8. OXYGEN	8. CMPTR	8. ENG HOT
9. OXYGEN	9. ALTITUDE LOW	9. OIL QTY	9. APP PWR CMPSTR
10. FUEL PUMP	10. CMPTR	10. ALTITUDE LOW	10. COUPLER OFF
11. ANTI-SKID	11. FUEL LOW	11. ECM INOP	11. TILT
12. RAD ALT	12. MASTER ARM	12. ENG HOT	12. FUEL PUMP
	13. ENG HOT	13. MASTER ARM	13. AFCS
	14. FUEL BOOST	14. FUEL PUMP	14. FUEL BOOST
	15. ECM INOP	15. IN RANGE	15. 10 SECONDS
	16. RAIN REMOVE HOT	16. SAM 3 (X)	16. LDG CHK
	17. IFF	17. SAM 2 (SRC)	17. WPN ARMED
	18. WING PRESSURE	18. SAM HI	18. RAD ALT OFF
	19. RADAR FAIL	19. READY TO FIRE	19. ACL READY
	20. IN RANGE	20. AAA	20. CMD CONTROL
	21. IR COOL	21. ROUNDS REMAINING	
	22. HUD HOT	22. FUEL BOOST	
	23. AOA OFF	23. AIR DATA CMPTR	
	24. ECM RPT	24. RADAR FAIL	
	25. ECM REC	25. OXYGEN	
	26. ARM (DATA LINK)	26. SHI	
		27. ECM RPT	
		28. SLO	
		29 HUD FAIL	
		30. AIW AIDAY	
		31. HUD HOT	
		32. WING PRESS	
		33. WHL/FLP	
		34. ECM REC	
		35. CHL	
		36. X-HI	
		37. X-LO	
		38. AIW	
		39. AIDAY	
		40. LORO	

SECTION 4
DISPLAY FORMAT EXPERIMENT

With the exception of various classes of avoidance information, most discrete information of a caution or warning nature is best presented visually by means of brief written messages on the HUD. From this basic premise, plus the assumption that only one such message at a time need ever be displayed on the HUD, an experiment was performed to determine the best size, location, and enhancement scheme to use.

4.1 Experimental Design

A subject-by-treatment, randomized block design was selected. Six subjects were used to obtain statistically stable data. The experimental treatments consisted of three messages, three character sizes, eleven locations, and three types of enhancement. A fourth type of enhancement (blinking) was informally evaluated throughout the experiment. The three messages were SAM HI, HYD PRESS, and FIRE. These three messages were initially selected as representative warnings necessary to achieve a disjunctive reaction time, i.e., messages that require reading prior to appropriate response. Experimental design also required control of message factors such as area illuminated on the retina, letters, letter frequency, and message content. This was primarily accomplished by separate statistical treatment of each of the three messages. Each statistical treatment was a four-dimensional analysis of variance.

Dependent variables were reaction time, message misses, and response errors. A two-dimensional error in a simultaneous tracking task was also monitored.

4.2 Apparatus

Figures 4-1 and 4-2 show the laboratory arrangement used for the experiment. Display material from four independent sources was superimposed on a rear projection screen, that both experimenter and subject could observe. The composite picture was viewed by the subject from an enclosed, light-controlled area through a large circular collimating lens. A dynamic real world view was provided by a 16-mm color motion picture (JTF-2 low level movies) using a standard projector modified with a high brightness (1200 watt) lamp, an iris diaphram, and a zoom lens. Fixed HUD display symbols were provided by a high resolution glass plate photo, projected by a GAF 35-mm projector, modified with a Kodak Wratten filter and a large aperture iris diaphram. Tracking symbols were generated electronically and projected from a stroke written

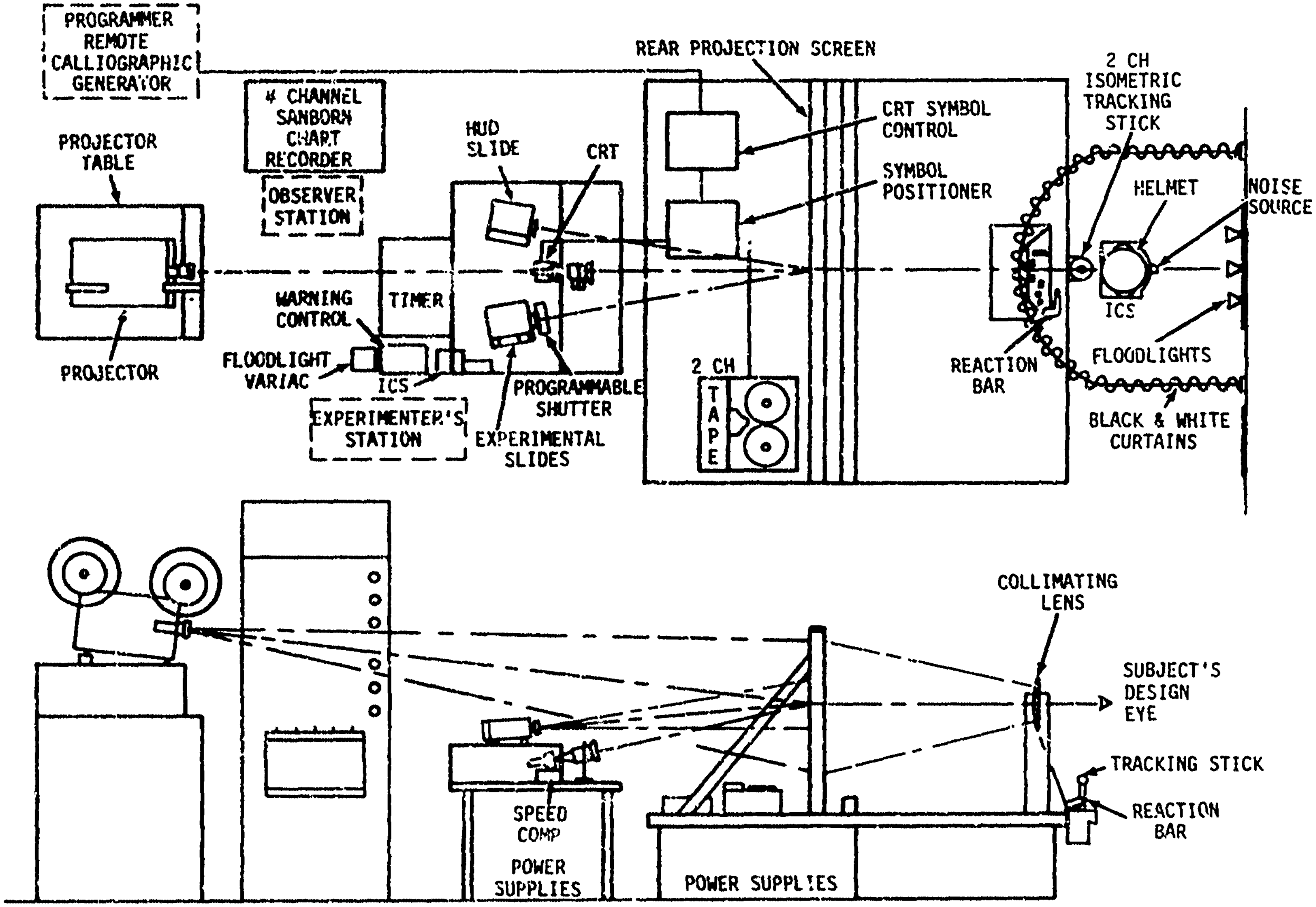


Figure 4-1. HUD Display Laboratory Arrangement

Figure 4-2. HUD Display Simulator

CRT (p-31 phosphor) by an f/1.18, 3-inch diameter lens. Experimental messages were provided by specially prepared 2-inch square, high-resolution, glass plates and a modified 35-mm GAF slide projector. This projector used an ILEX shutter, set for a remotely triggered 1/30 second exposure. At the experimenters option, an electronic programmer could drive the ILEX shutter, producing blinking at 3 Hz. In all cases, rise and decay time was less than 1/250 of a second, so that exposures were well controlled. A four-channel Sanborn recorder and a precision counter/timer indicated the experimental data. Controls for the subject included lighted legend pushbutton switches and a two-axis isometric controller as shown in Figure 4-2.

Table 4-1 is a complete listing of laboratory elements.

4.3 Display Material

The background real world view was a color motion picture film of low level terrain, taken from the aft of an A-3 type aircraft. The film was run backwards to give the illusion of forward flight. The film subtended a 36° field.

An A-7E HUD display, without dynamic elements, formed the fixed portion of the HUD display. The source was a GAF, 500-watt, 35-mm slide projector equipped with an iris to set brightness level without affecting color. A single 2x2-inch high-resolution, glass plate photograph of HUD symbol artwork was used. Size was approximately 14° x 18° (visual field). Strokes were 1 milliradian. Figure 4-3 illustrates the static HUD display.

Visual cues for the two-dimensional compensatory tracking task were provided by a miniature stroke-write CRT indicator and projection lens. The symbols were generated and positioned electronically. The aircraft symbol remained fixed. The moving flight command box was driven in X and Y by two opposed sources operating in parallel. The error source was a prerecorded randomized disturbance function in X and Y, played back by a stereo tape deck. The operator provided nulling function using an isometric, two-axis hand controller. The range of movement was limited to the central 16 degrees of visual field, but normal practice and the error function restricted movement of the box to the central 1.5°.

The disturbing function for the tracking task was derived from a table of random numbers; the function moves the distrubed symbol in a random sequence to the designated positions in Figure 4-4. The function was generated with aid of the joystick and displayed tracking symbols and recorded on a two-channel audio tape recorder. A former A-4 pilot judged the task and apparatus to be "very realistic - similar to low level flying with moderate turbulence."

Table 4-1. Display Laboratory Equipment List

COMMERCIAL EQUIPMENT
1. SANBORN 4-channel recorder
2. SYSTRON DONNER timer/counter Model 6151
3. GAF 1680 remote controlled, 2x2-inch slide projector (2)
4. FANON ECHOMASTER Intercom
5. Sony TC-353D Stereo Tape Recorder/Player
6. Projection lens, Pan-Tachar f/1.18, 150-inch focal length
7. ILEX No. 3 Synchro Electronic Shutter, with speed computer
8. White curtain
9. Black curtain
10. Kodak Wratten 3x3-inch red and green gelatin filters (6)
11. Chair and footrest
12. Variac and photoflood lights
13. KERN DKM2 Theodolite
14. 11.25-inch focal length collimating lens
15. GENTEX DH-115 helmet
16. Polacoat 30x40-inch lenscreen LS60NPL, 3/16", and frame
17. 400 Hz Muffin Fan
18. Laboratory Power Supplies
NORDEN BUILT EQUIPMENT
1. Instrument panel, lens holder, reaction controls, and helmet positioner
2. Unit 1 - experimenters controls
3. Unit 2 - shutter programmer
4. Unit 3 - symbol positioner
5. Unit 4 - symbol brightness, position and size control, and symbol junction box
6. Unit 5 - calliographic/vector generator
7. Unit 6 - calliographic generator driver
8. Unit 7 - 3-inch miniature CRT indicator

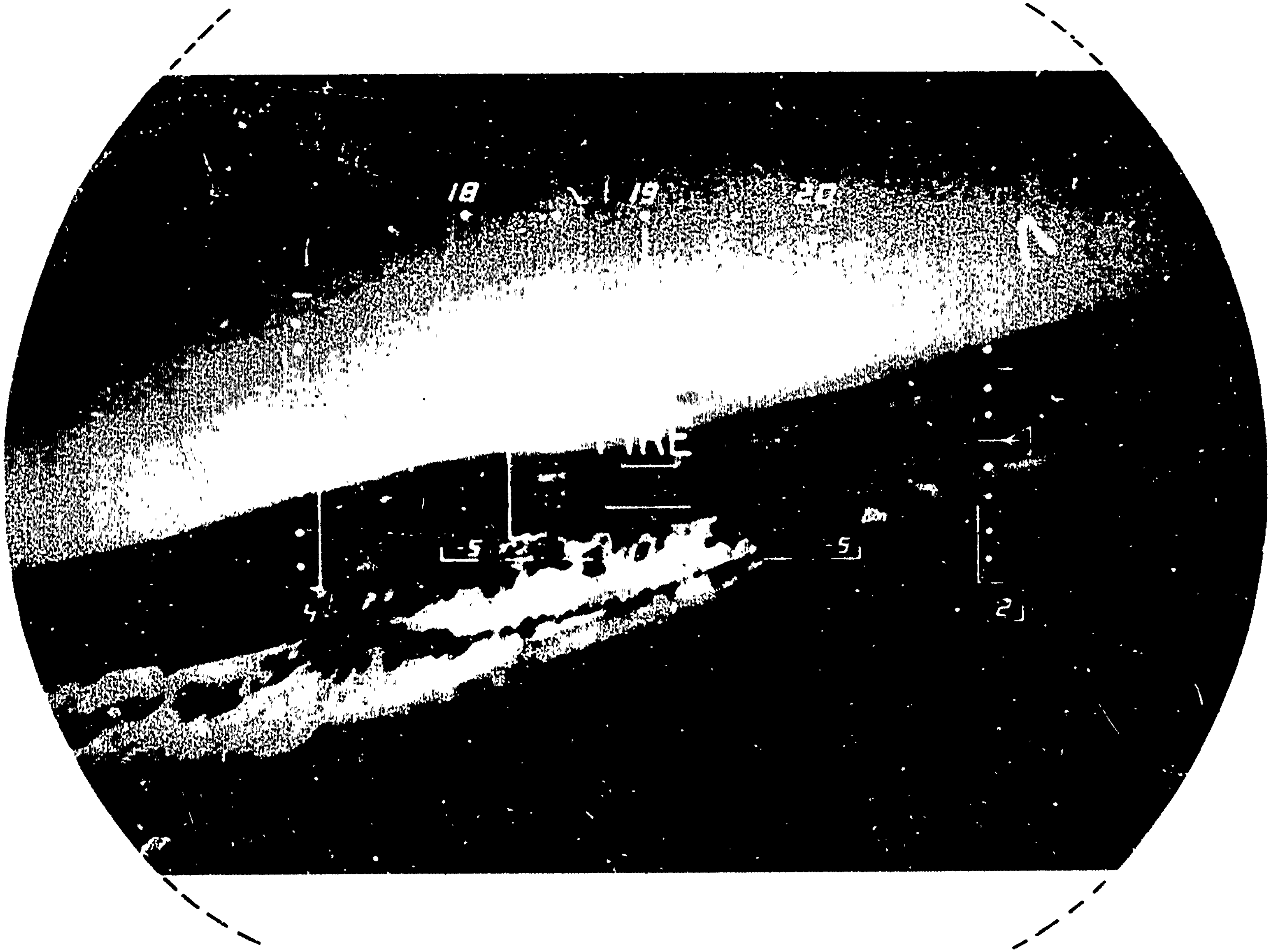


Figure 4-3. HUD Display (36° IFOV with Motion and Color; Tracking Symbols Omitted)

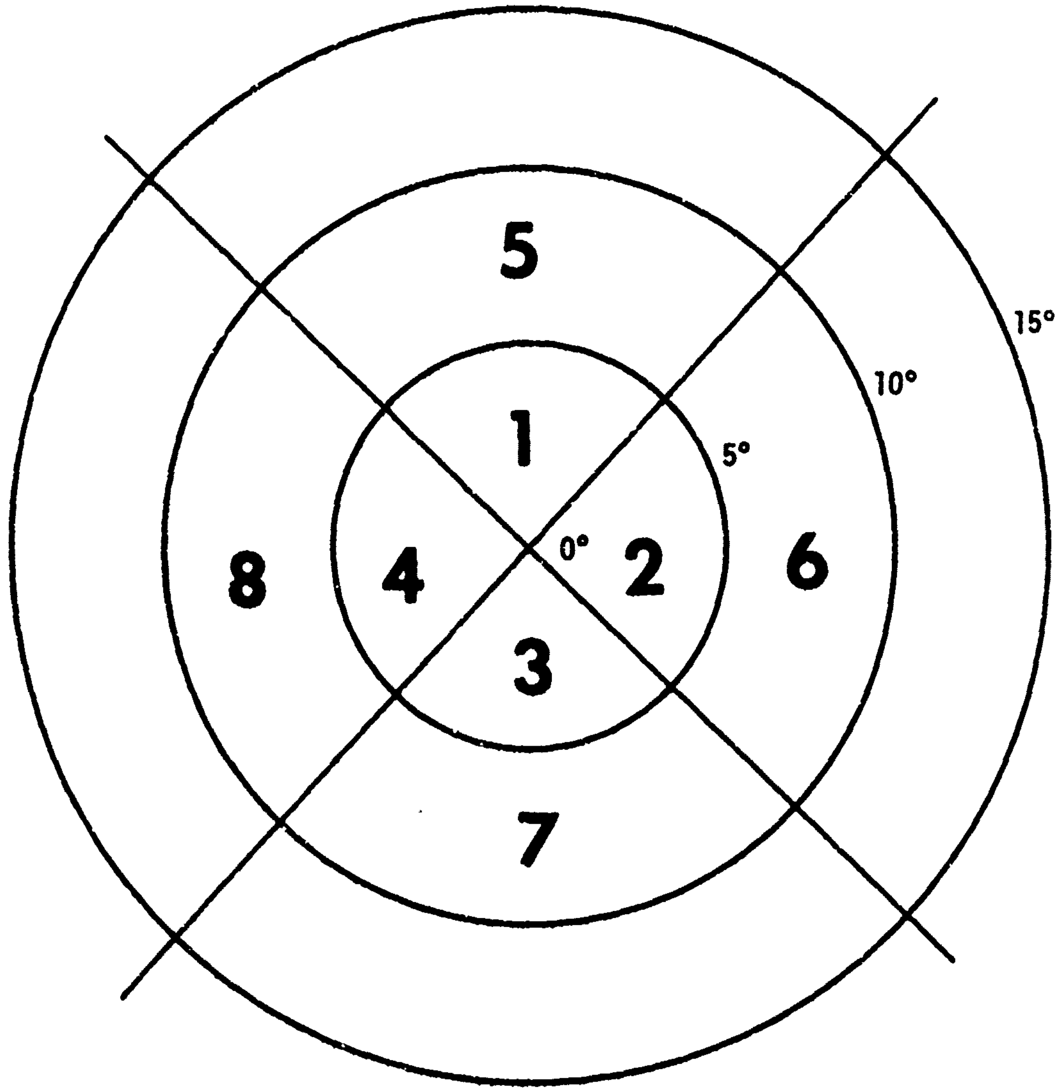


Figure 4-4. Eight Positions for Tracking Symbol
(Selected at Random from Random Number Table)

The experimental material consisted of 99 2x2-inch, high-resolution, glass plates (3 messages x 11 locations x 3 character heights). The three sizes were 1/2°, 1°, and 2° (character height). See Figure 4-5. The three messages were designed for high legibility: 3:2 aspect ratio (height to width); 10:1 height-to-stroke width ratio; character horizontal spacing of 1/2 character height. Figure 4-6 illustrates the locations selected.

4.4 Subjects

Six male subjects were chosen from the Norden technical staff. Nonpilot personnel were selected because of their availability. Accordingly, the experimental tasks were designed so that the required skills were easily acquired, yet the tasks were similar to pilot flight tasks. Uncorrected normal vision was required, and age limits of 20 to 30 were imposed. Each candidate subject was screened by the Norden medical staff for normal acuity, both central and peripheral, and normal color and depth perception.

4.5 Procedure

Subjects were seated at a simulated instrument panel with controls and lighted pushbutton switches. They viewed the real world scene and superimposed HUD display through a collimating lens porthole. The porthole was surrounded by a flood-lit, non-glare, white curtain covering ±35° (elevation) by ±100° (azimuth) at the observer's eye.

Prior to each session, the brightness of each display element was measured and adjusted using a Prichard photometer. Each subject was moved to the design eye position in order to control image size and position in his field of view. The display was surveyed using a Kern theodolite to control display size and location.

Once seated at design eye, standard instructions were read via the intercom to each subject. (Refer to Appendix C.) They consisted of an explanation of the overall purpose of the experiment, the tracking and visual detection tasks, and the manner in which they were to indicate their response to the warning signals. Subject interest was high. Motivation was controlled by demonstrating to each subject that his reactions were being continuously measured and recorded on the tracking and message response tasks, and that he was in a sense competing with the other subjects. Knowledge of the other subjects performance, however, was not revealed until after all subjects had completed the experimental trials.

SAM HI   FIRE   HYD PRESS

SAM HI   FIRE   HYD PRESS

SAM HI   FIRE   HYD PRESS

Figure 4-5. Experimental Warnings

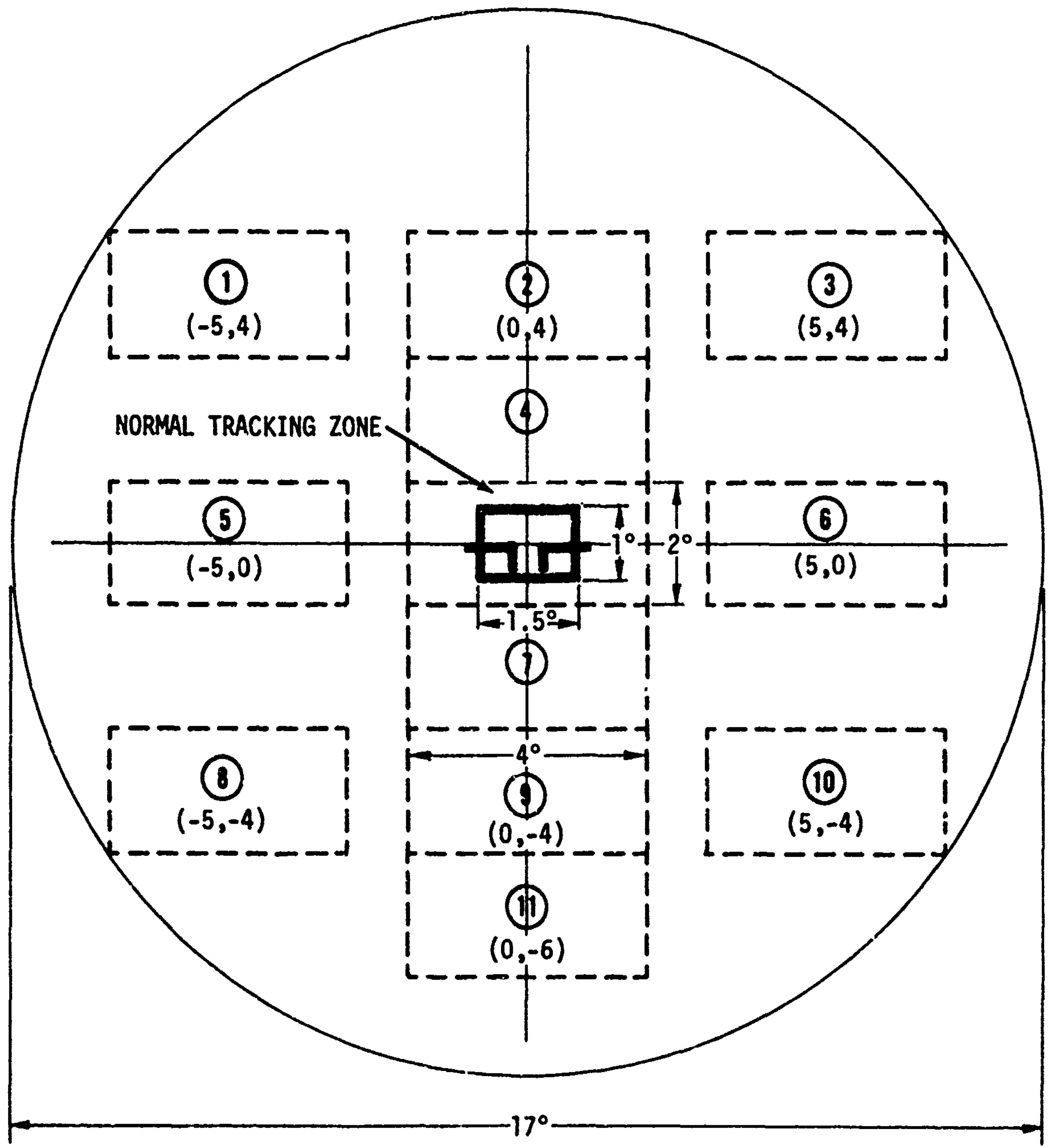


Figure 4-6. Tracking Symbols and Warning Locations

All combinations of the independent variables were presented in random order, once to each subject. The random order was used to minimize practice, fatigue, and order effects upon the experimental results. Each experimental session required five minutes of warmup and approximately 35 minutes of experimental time. In addition to initial practice and familiarization periods, each subject received three experimental sessions corresponding to three coding enhancement conditions: (1) balanced brightness warning messages (12 footlamberts); (2) brighter warning messages (24 footlamberts), with remaining symbols at 12 footlamberts; and (3) red warning messages with remaining symbols green (all at 12 footlamberts). Brightness was controlled by an iris diaphragm. Color was introduced by dropping a suitable transparent filter in the light path. Blinking was introduced by programming the ILEX shutter so that the presentation was interrupted three times per second with equal on and off intervals. The normal experimental presentation was a 1/30-second controlled exposure. This brief (tachistroscopic) exposure standardized and controlled the input warning stimulation so that the difficulty level for reading messages was high; therefore, differences in reading were magnified and easier to detect. Without this tachistroscopic technique, performance essentially disappeared; a subject's performance tended to stabilize at a given value for all stimulus conditions, and any remaining differences were small and essentially random.

Throughout the experiment, whenever a miss or error occurred, the message would be blinked. When this was done, a prompt and correct response was always obtained, indicating that blinking is the single most powerful technique for enhancing the detectability of messages. The criterion for a miss was an elapse of 4 seconds without a response.

Fatigue was controlled by observing the subject's performance during the trials, periodically asking him if he felt all right and wanted to continue. It was also controlled on a day to day basis by observation and questioning. When the subject's condition was below par, experimental sessions were delayed.

Motivation was also controlled by verbal communication between experimenter and subject based on the subject's observation of targets and his verbal response to the task. The entire display was observable by both experimenter and subject. If targets were missed (not called out) for a period of approximately 30 seconds, the experimenter would mention this to the

subject. Each subject was encouraged to develop a running commentary on the external world (aerial film). It was fairly easy to detect lapses in this dialogue during the experimental sessions. Anticipation of warnings from auditory cues (from the shutter) was eliminated by introducing 400 Hz fan noise coupled to the subject's hearing through the head positioner and helmet. Subjects reported that this sounded like they were in an operating aircraft and they could not hear the apparatus or people in the lab. Temporal anticipation was eliminated by introducing a predetermined random time interval between warning presentations.

Subjects were allowed to practice until a stable level of performance in the tracking task was achieved. The criteria for this performance was 60 minutes elevation, and ±30 minutes azimuth. The initial practice period was 20 minutes; subsequent warmups preceeding each 35 minute experimental session averaged 5 minutes. Each subject rested a minimum of 15 minutes out of the laboratory between sessions; in no case were more than two sessions administered to a subject in one day. Generally, one session per day was given each subject.

4.6 Recording of Data

Data from the experiment was recorded in two ways. Warning reaction times, errors, and misses were recorded manually by the experimenter using a direct digital readout. A complete record of all sessions was made and witnessed by a technician using the multichannel stylus recorder. Two channels of the recorder were driven by the tracking error signals in X and Y. Channel 3 recorded the time of the warning message stimulus; channel 4 recorded the subject reaction time. One-second timing marks are along the right hand side of the recorder. The technician annotated the records to identify the session, subject, time and date, subject errors, misses, and any equipment failures or other significant events. These raw records were provided to ONR at contract completion.

4.7 Data Analysis Procedure

The reaction time and error data were transposed from the original scoring sheets into three 6 x 99 matrices. The three matrices corresponded to the three messages - the six rows corresponding to results for the six subjects, and the 99 columns corresponding to the 99 combinations of message size, location, and enhancement. The raw data was provided separately to ONR.

The matrix format lends itself to the basic experimental design and to a standard four-way analysis of variance. As mentioned earlier, the analysis could not reasonably lump performance measures of the three messages without confounding the results with uncontrolled message factors. Thus, there are three data matrices, one for each of the three messages. The uncontrolled message factors that could have otherwise influenced performance were: area of the retina stimulated, number of individual letters, message content, subject familiarity (stereotyped reaction), letter arrangement, readability of individual letters, and area of the message block.

The data matrices were placed in core and disc memory of an IBM 370-155-5 12K core in GPSS format using a 2250 video terminal. One person read the scores in sequence from left to right and top to bottom while another operated the terminal and observed the display prior to permanent storage. Thus, 1800 four-digit decimal numbers were entered and stored in 2 hours (4 manhours) with high accuracy and confidence. This approach is recommended as fast, accurate, and efficient. Using the GPSS language and available subroutines, the various population means, error scores, range of values, and standard deviations across the independent parameters were calculated and printed out for each message matrix. From those calculations mean reaction times and errors as a function of size and other test parameters were obtained. These results are discussed in section 4.8.

After obtaining the means, errors, and distributions of the individual parameters for each message group, a four-dimensional analysis of variance was conducted to test the hypotheses that the various treatment differences were due merely to chance. The data treatment was extrapolated from a three-dimensional analysis (Lindguist, "Design and Analysis of Experiments," Houghton Mifflin, 1953). A computer program was written in PL-1 to calculate the variance estimates and their interactions for all treatments. A small program was also written to convert the raw scores from GPSS format to PL-1 decimal format. The four-way analysis program was initially tested with two precalculated textbook examples; agreement of results was achieved to eight decimal places. The results of the analysis of variance are discussed in section 4.9.

4.8 Results

4.8.1 Character Size

Mean reaction time and total errors as a function of character height are plotted in Figure 4-7. All curves are concave upward, with a knee at approximately one degree; this suggests that this character size is suitable as a compromise between detectability and display clutter.

The analysis of variance (see section 4.9) shows that the differences in mean reaction time are significant for one message (FIRE). The total error curves in Figure 4-7, however, appear to be particularly sensitive to character height and are well correlated for the three messages. The knee appears once again at one degree. Since the experiment was designed to test reaction time, there was no systematic method for testing the significance of the differences in total error scores. These results, however, provide particularly persuasive evidence for establishing a guideline of one degree minimum character height.

In the reaction time results, the times obtained for the three messages show some significant differences. This may be due to one or more of several causes. FIRE, for example, was the shortest message in the experiment; the subjects probably read it more quickly, enabling them to respond more quickly (although not more reliably, as indicated by the error scores).

Responses to HYD PRESS were uniformly faster than to SAM HI. This might be explained by the fact that HYD PRESS was the only two-line message - a fact that the subjects probably learned; of the two more complex messages, they were thus able to respond more quickly to the message with the distinctive shape. This experimental difference between SAM HI and HYD PRESS can be expected to vanish in an operational system, where the far greater number of messages and the lower frequency at which they appear will preclude the operator from learning message shapes.

Data of Figure 4-7 are plotted in Figure 4-8 as a function of illuminated message area. These curves are in no sense better correlated than the curves of Figure 4-7. This suggests that character height is at least an equivalent, and probably a superior parameter, for specifying message size.

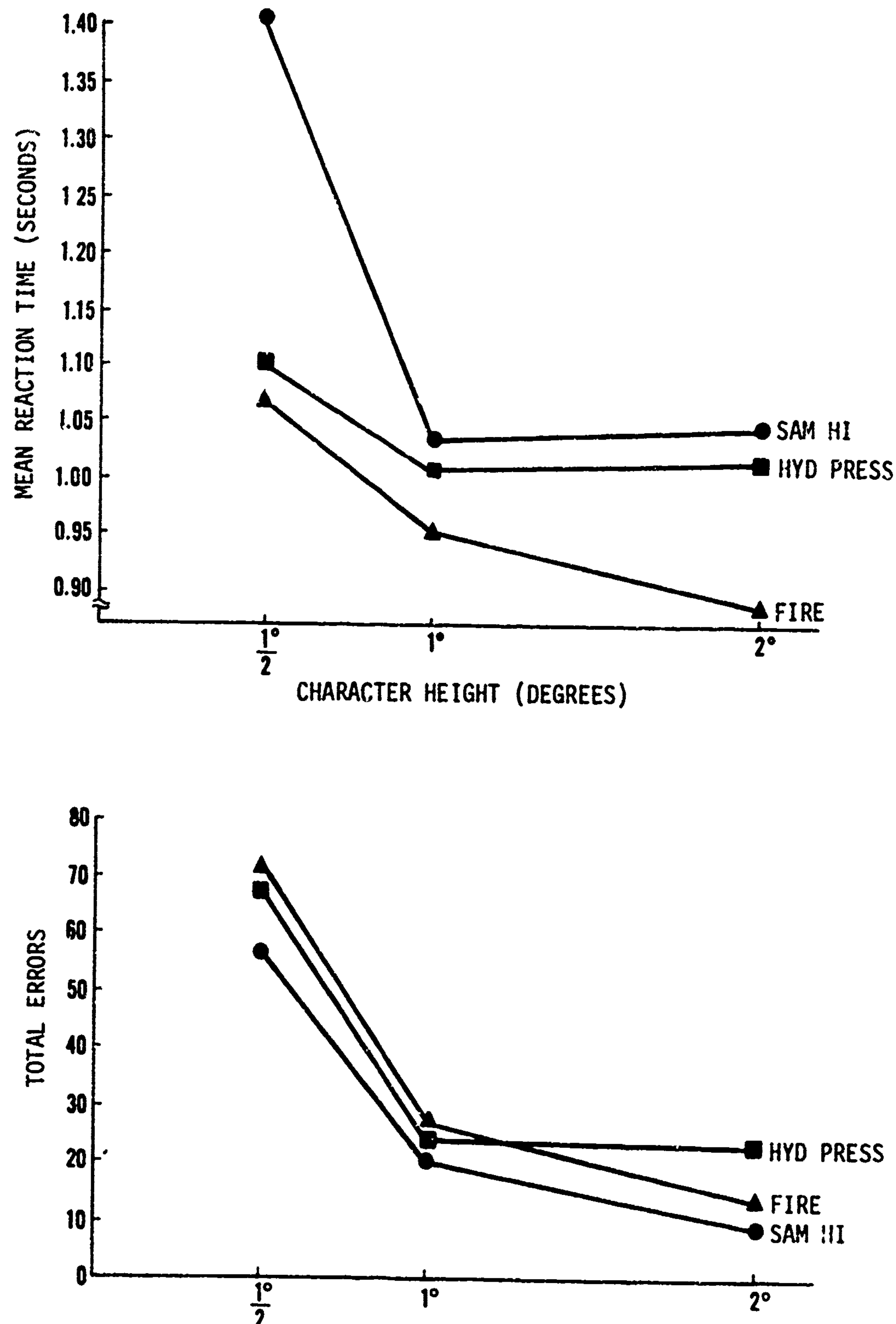


Figure 4-7. Character Height

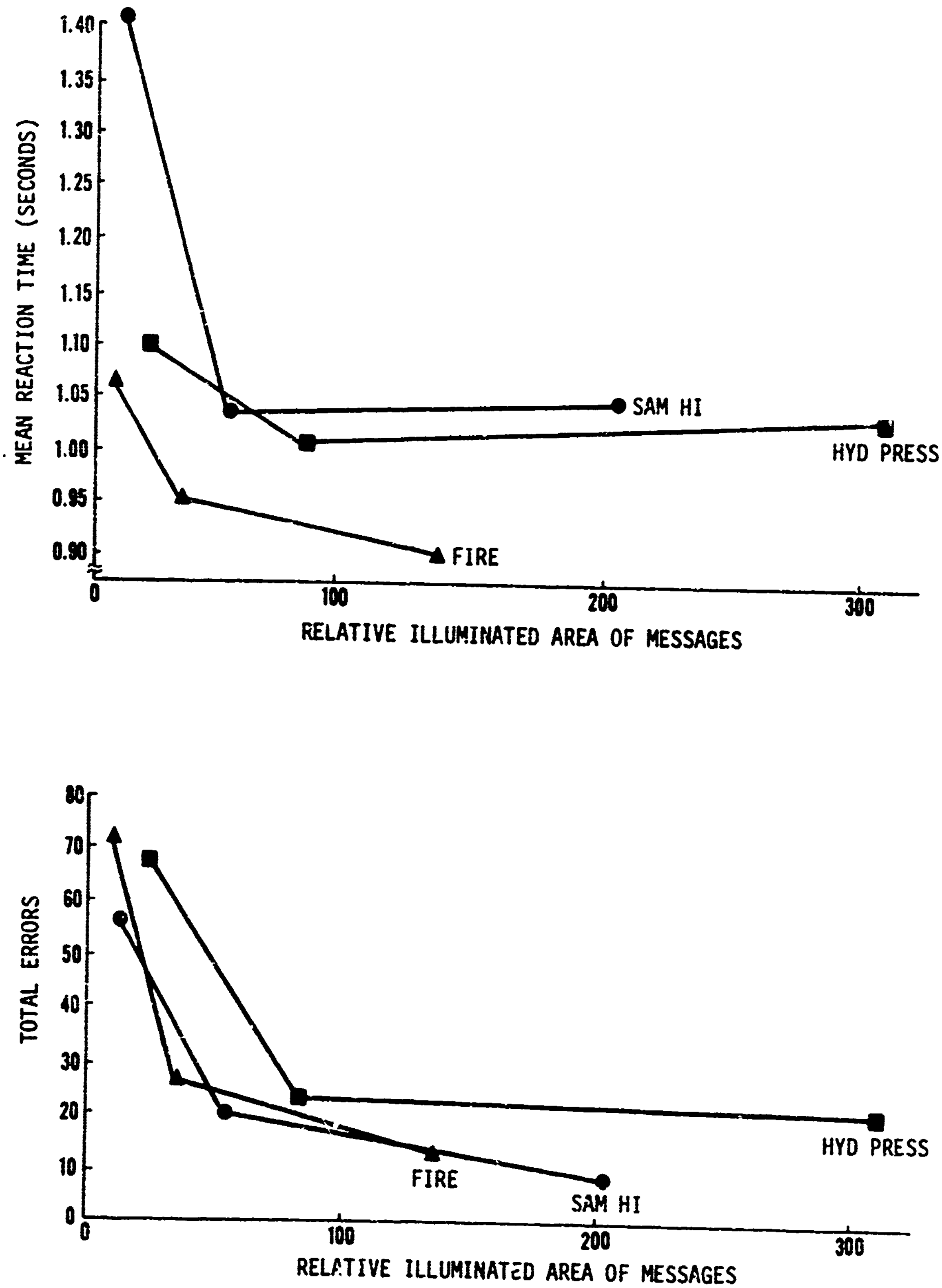


Figure 4-8. Illuminated Message Area

4.8.2 Message Location

Performance was also measured as a function of message location. Eleven different locations were tested. In selecting locations, both the center and the far periphery were avoided - the center to assure visibility along boresight and the far periphery to assure acceptable responses to the messages.

Mean reaction times and mean error scores were obtained as a function of message location. These data are shown for each message in Figures 4-9, 4-10, and 4-11. The literature had suggested that performance would be best along the horizon and in the lower half of the visual hemisphere. Our data bear this out. Good performance is achieved up to ±8 degrees along the horizon. Along the central vertical, performance is good up to +4 degrees elevation and down to -8 degrees. A performance anomaly is observed for HYD PRESS and FIRE at the -4 degree location, which might be explained by motion interference from the background film. Performance definitely appears to degrade for locations off the two orthagonal axes.

It seems likely, therefore, that locations along the orthogonal axes receive proportionally more visual attention, the degree of attention becoming much less beyond about 6 degrees from the center. The reason for the horizontal preference might be that the subject attends to the horizon to check attitude information and because of ease and familiarity of horizontal eye scanning behavior. The preference for the central vertical might be related to the natural tendency to attend the direction (path) of movement. The preference for the lower hemisphere may be due to the visual detail available and the attention getting value of the motion in the background film combined with the importance of ground clearance, stereotyped behavior, and trends toward the natural rest orientation of the head and eye.

In summary, good locations for visual messages are illustrated in Figure 4-12. It is of interest that the surveyed pilots, in the responses to the questionnaire (Appendix B), selected the two positions on the vertical axis as preferred locations. Our findings substantiate this choice and indicate even better performance with the two horizontal locations.

The analysis of variance for location (section 4.9) again shows significance only for FIRE. It is of interest, however, that for the other two messages, the size-by-location interaction shows significance. This indicates that in all cases there are preferred combinations of size and location, but that the statistical analysis was not capable of separating these effects in all cases. The fact that location changes as message size changes is illustrated in Figure 4-13.

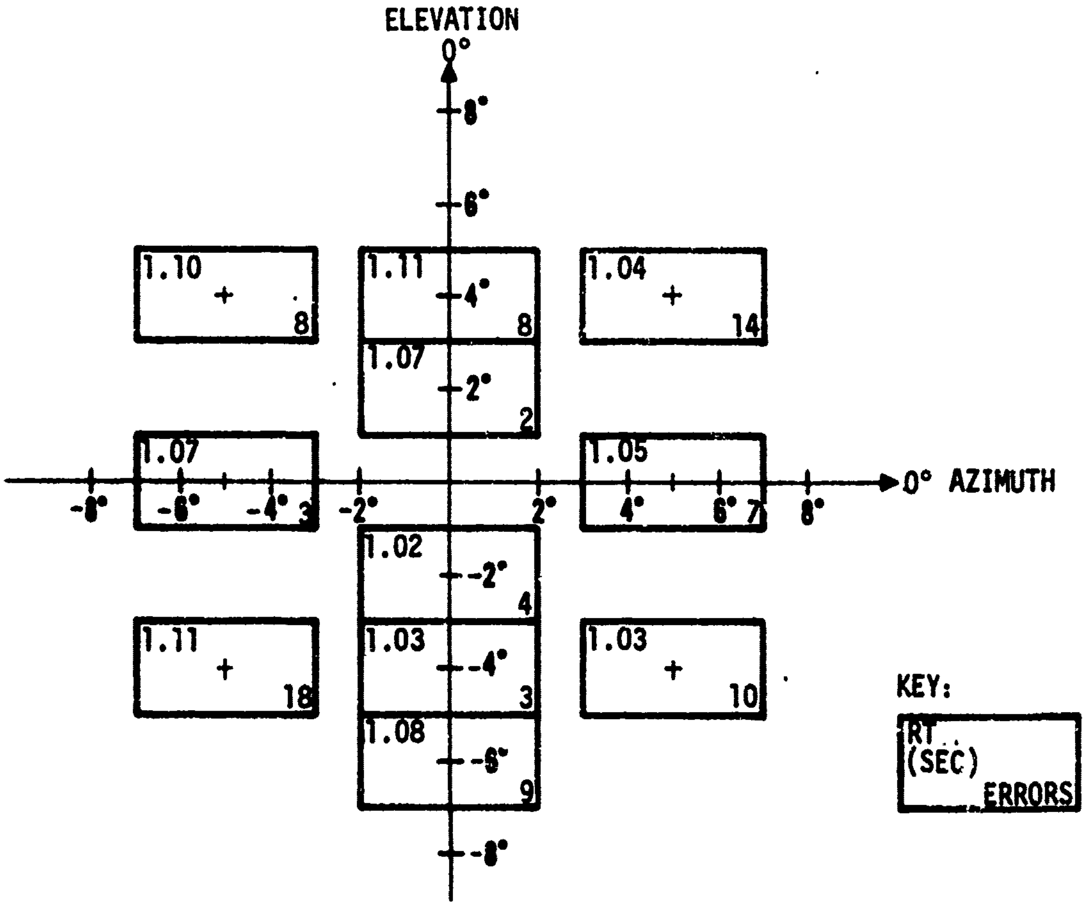


Figure 4-9. Location (SAM HI)

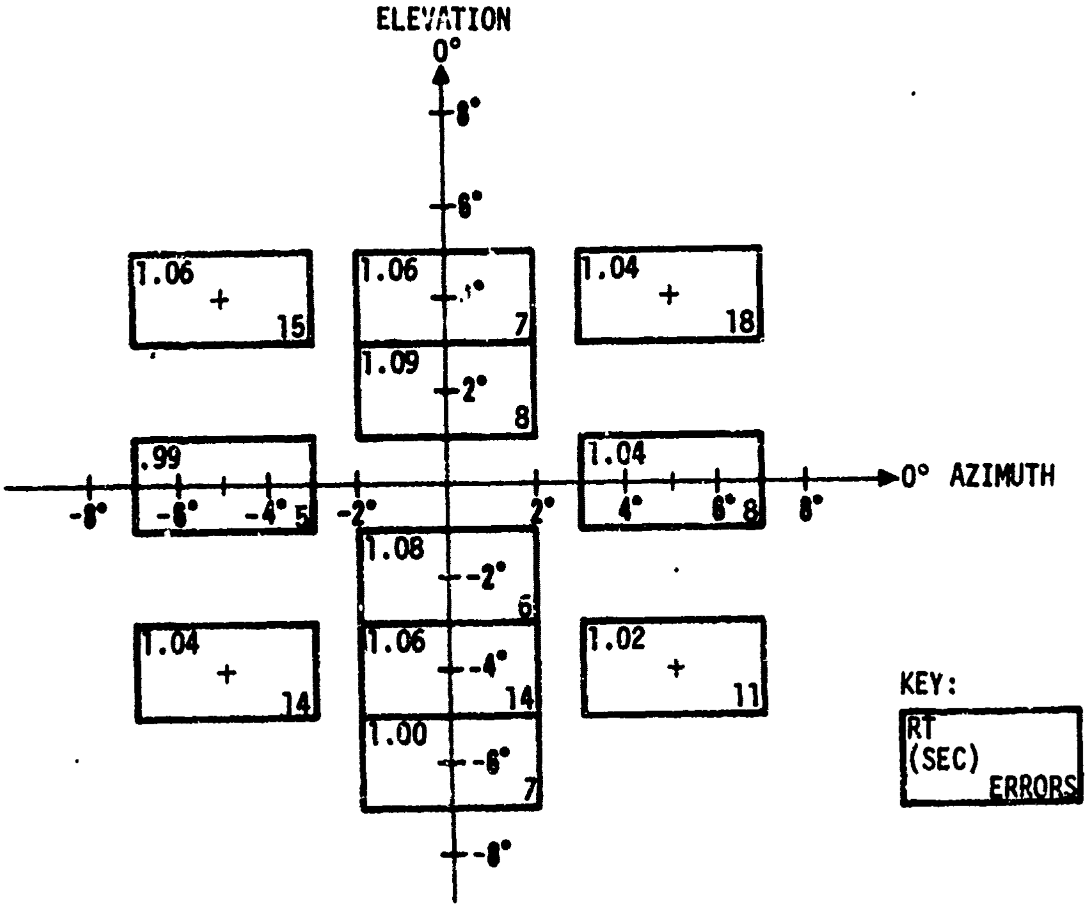


Figure 4-10. Location (HYD PRESS)

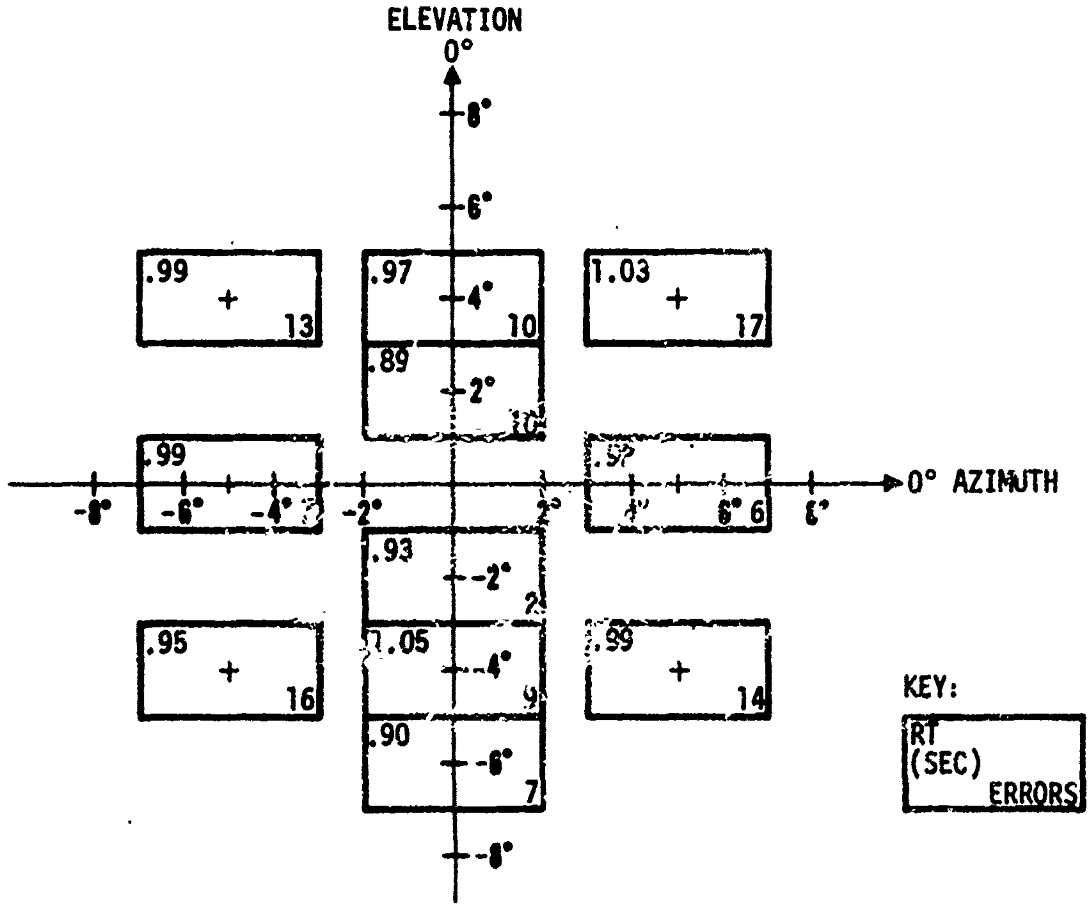


Figure 4-11. Location (FIRE)

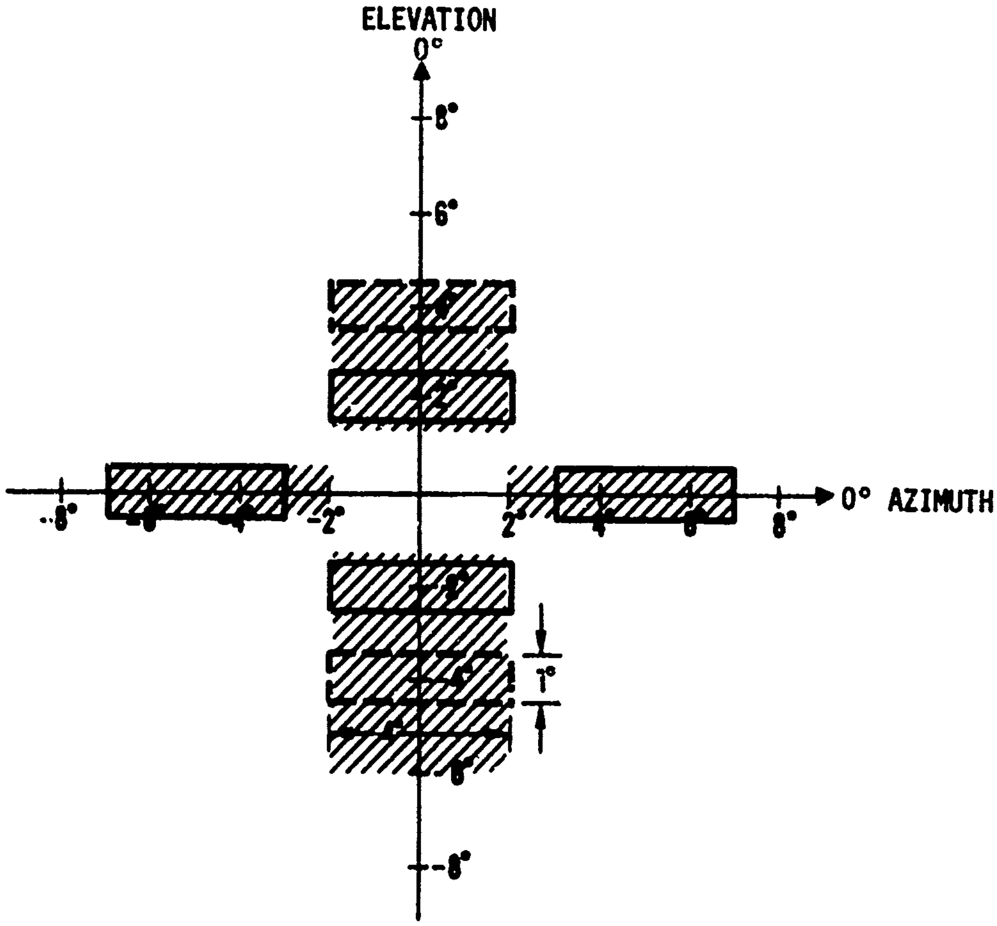
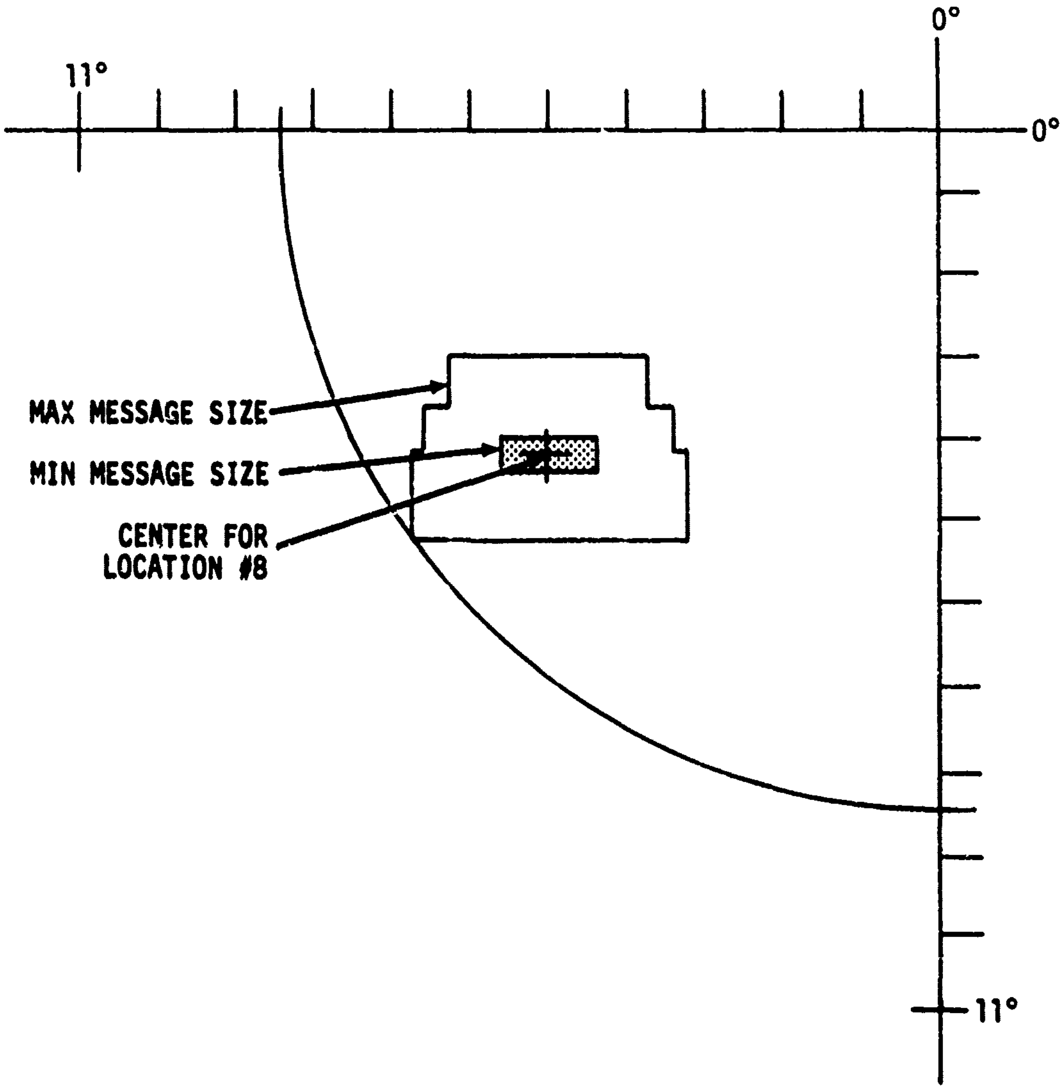


Figure 4-12. Preferred Warning Message Location



MIN SIZE IS FIRE AT 1/2 DEGREE CHARACTER HEIGHT.

MAX SIZE IS COMPOSITE OF SAM HI & HYD PRESS
AT 2° CHARACTER HEIGHT

Figure 4-13. Interaction of Size and Location

The most striking differences appear when scores are separated according to location on and off the orthogonal axes. See Figure 4-14. From these data, it is apparent that on-axes locations are markedly superior for detecting and accurately reading messages (or targets). Performance (errors and misses) is approximately twice as good for locations on the orthogonal axes.

4.8.3 Color and Brightness Enhancement

Mean reaction times and errors as a function of coding enhancement are plotted in Figure 4-15. The reaction time curves suggest that performance improves when either brightness or color enhancement is used. Brightness appears superior to color, and both superior to the unenhanced case. The analysis of variance (section 4.9) showed no significance at the 95% point in these results, so that they must be regarded as unsubstantiated.

4.9 Analysis of Variance

The results of three four-dimensional analyses are summarized in Figures 4-16, 4-17, and 4-18.

The analyses show that variations are significant for some, but for far less than all effects. As discussed in section 4.8, there was significance for size or location, or the interaction of both in all cases; the statistical analysis was not always capable of separating the effects for the limited ranges of the variables being tested. (These ranges of size and location were based on acceptable limits described in the literature.) However, the significance of the reaction time results that were obtained, combined with the striking variations in error scores (whose significance could not be tested), provides substantial justification for the recommended sizes and locations. There is also some indication of the value of brightness and color coding, but here the results are less conclusive since they are not substantiated by either statistically significant variations in reaction time or large variation in error scores.

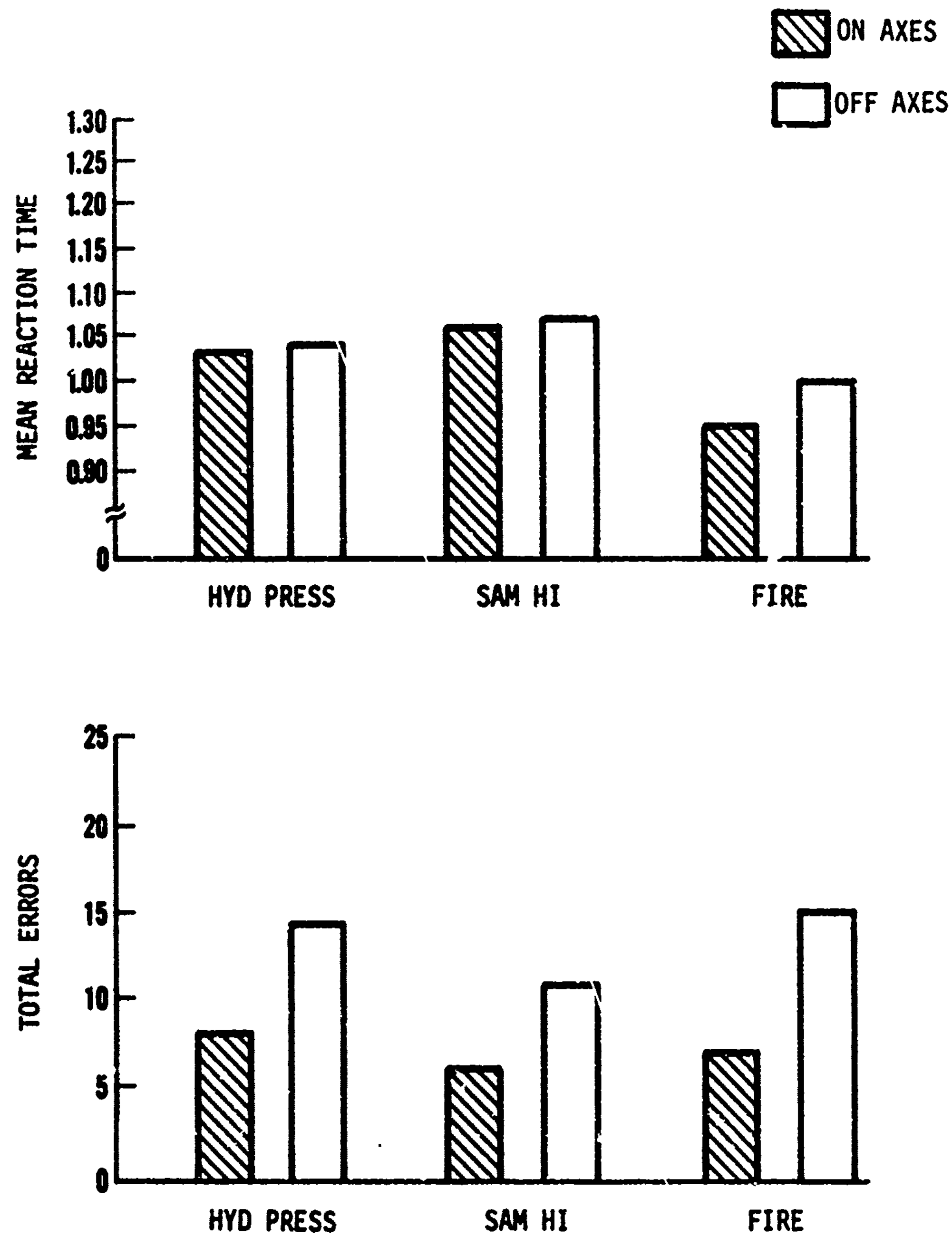


Figure 4-14. Performance for On-Axes vs Off-Axes Locations

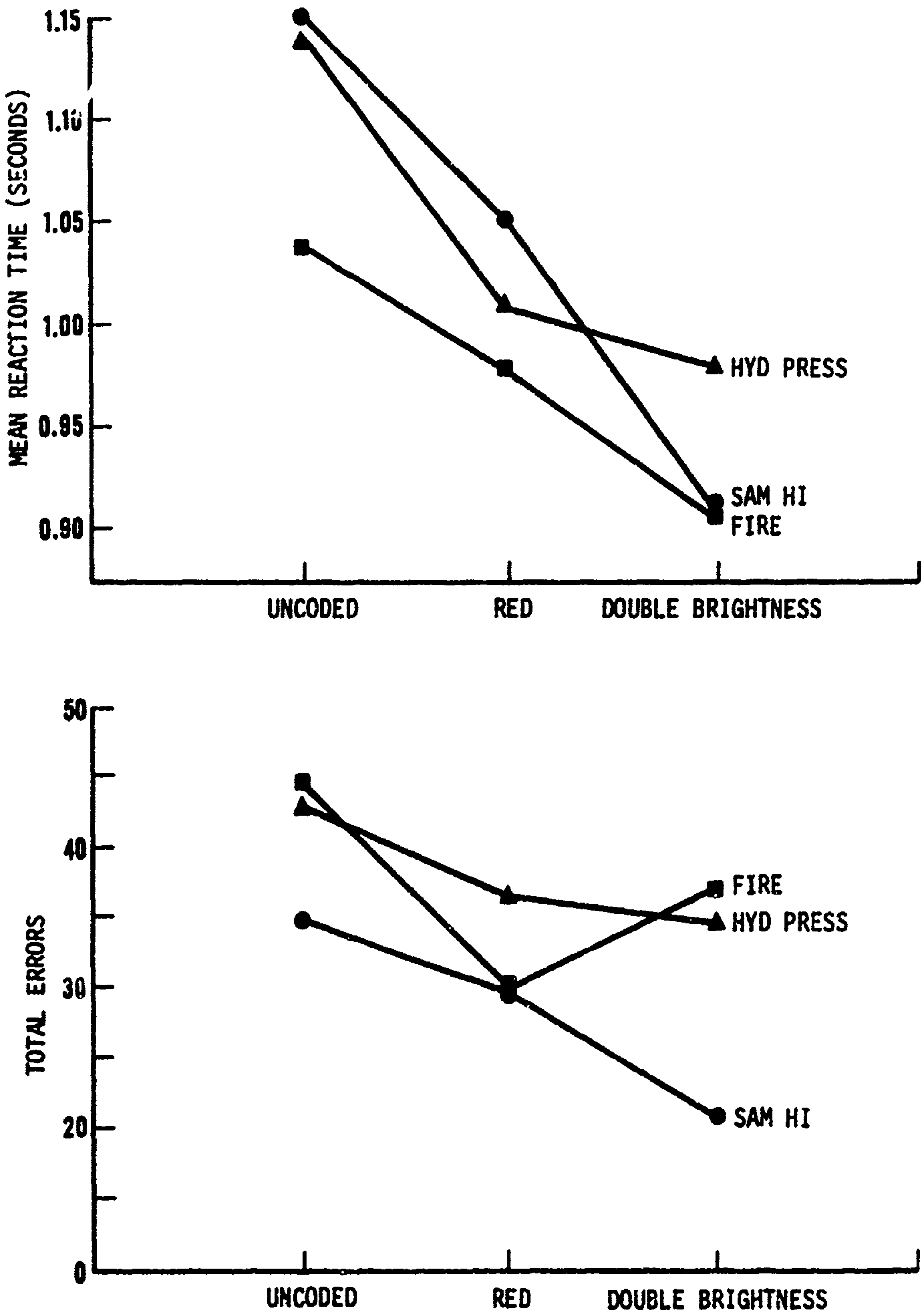


Figure 4-15. Coding Enhancement Scheme

SOURCE	DF	SS	MS	F	F_{05} *	F_{01} **
0	5	8.848	1.7696			
S	2	0.525	0.2623	2.670	4.10	
L	10	0.508	0.0508	0.863	2.02	
Z	2	2.152	1.0758	2.300	4.10	
OxS	10	0.9827	0.09827			
OxL	50	2.9427	0.05885			
OxZ	10	4.6767	0.4677			
*SxL	20	2.3997	0.1200	2.178**	1.68	2.06
SxZ	4	0.2288	0.0572	1.370	2.87	
LxZ	20	0.6481	0.0324	0.577	1.68	
OxSxL	100	5.5083	0.0551			
OxSxZ	20	0.8347	0.0417			
OxLxZ	100	5.6184	0.0562			
*SxLxZ	40	4.4462	0.1116	4.751**	1.55	1.88
OxSxLxZ	200	4.6795	0.0234			
TOTAL	593	44.9982				

* SIGNIFICANT EFFECT AT 95% CONFIDENCE LEVEL
** SIGNIFICANT EFFECT AT 99% CONFIDENCE LEVEL

Figure 4-16. Results of Analysis of Variance for Experiment 1 - SAM HI

SOURCE	DF	SS	MS	F	F_{05} *	F_{01} **
0	5	1.693	0.339			
*S	2	2.165	1.082	60.628**	4.10	7.56
*L	10	1.221	0.122	3.291**	2.02	2.70
Z	2	1.320	0.660	2.533	4.10	
OxS	10	0.176	0.0176			
OxL	50	1.855	0.0371			
OxZ	10	2.606	0.2606			
SxL	20	1.706	0.0853	1.669	1.68	2.06
SxZ	4	0.361	0.0902	1.232	2.87	
LxZ	20	0.784	0.0392	0.896	1.68	
OxSxL	100	5.113	0.0511			
OxSxZ	20	1.065	0.0732			
OxLxZ	100	4.374	0.0437			
*SxLxZ	40	2.669	0.0667	16.320**	1.55	1.88
OxSxLxZ	200	0.818	0.00409			
TOTAL	593	28.329				

* SIGNIFICANT EFFECT AT 95% CONFIDENCE LEVEL
** SIGNIFICANT EFFECT AT 99% CONFIDENCE LEVEL

Figure 4-17. Results of Analysis of Variance for Experiment 1 - FIRE

SOURCE	DF	SS	MS	F	F_{05}*	F_{01}**
O	5	4.692	0.938			
S	2	0.696	0.348	3.189	4.10	7.56
L	10	4.699	4.699	1.074	2.02	2.70
Z	2	2.094	1.047	2.689	4.10	
OxS	10	1.091	0.109			
OxL	50	2.187	0.0437			
OxZ	10	3.094	0.3894			
*SxL	20	1.519	0.0759	1.796*	1.68	2.06
SxZ	4	0.546	0.137	2.328	2.87	
*LxZ	20	1.008	0.0504	1.786*	1.68	2.06
OxSxL	100	4.229	0.0423			
OxSxZ	20	1.173	0.0587			
OxLxZ	100	2.823	0.0282			
*SxLxZ	40	1.984	0.0496	8.052**	1.55	1.88
OxSxLxZ	200	1.232	0.00616			
TOTAL	593	29.638				

* SIGNIFICANT EFFECT AT 95% CONFIDENCE LEVEL
** SIGNIFICANT EFFECT AT 99% CONFIDENCE LEVEL

Figure 4-18. Results of Analysis of Variance for Experiment 1 - HYD PRESS

SECTION 5
SYSTEM SIMULATION

The final step in the program for defining and developing information and display format requirements was dynamic display evaluation, and demonstration. The evaluation was planned to ensure compatibility of the HUD warning system with the primary pilot tasks of flight control and weapon delivery. In addition, it was planned to test the basic premise that a word message HUD warning system was superior to the general alerting system presently used. This premise was to be tested using Navy pilot performance and opinion under realistic conditions.

Dynamic simulation of the display and the vehicle performance, with the pilot in the control loop, is key to this evaluation. A block diagram of the system simulation is presented in Figure 5-1. The major elements of the system include:

a. a HUD indicator, which displays aircraft situation, status, and command information to the pilot.

b. F-9F cockpit, aircraft controls, lighted legend displays, and warning reaction controls

c. vehicle dynamic simulation, using twin PACE 231R computers

d. an ANALOGIC analog-to-digital converter (adc) and multiplexer that converts aircraft performance functions and the external command steering and warning signals to digital form

e. a VARIAN 620/f digital minicomputer, which controls and positions and refreshes the display symbols

f. a HUD symbol generator that converts computer commands to specific video deflection and brightness signals

g. experimenter's controls to select and introduce one or more warning messages and to introduce the command steering signals or turbulence that affect pilot workload

Figure 5-2 shows the cockpit and Figure 5-3 shows the supporting simulation equipment.

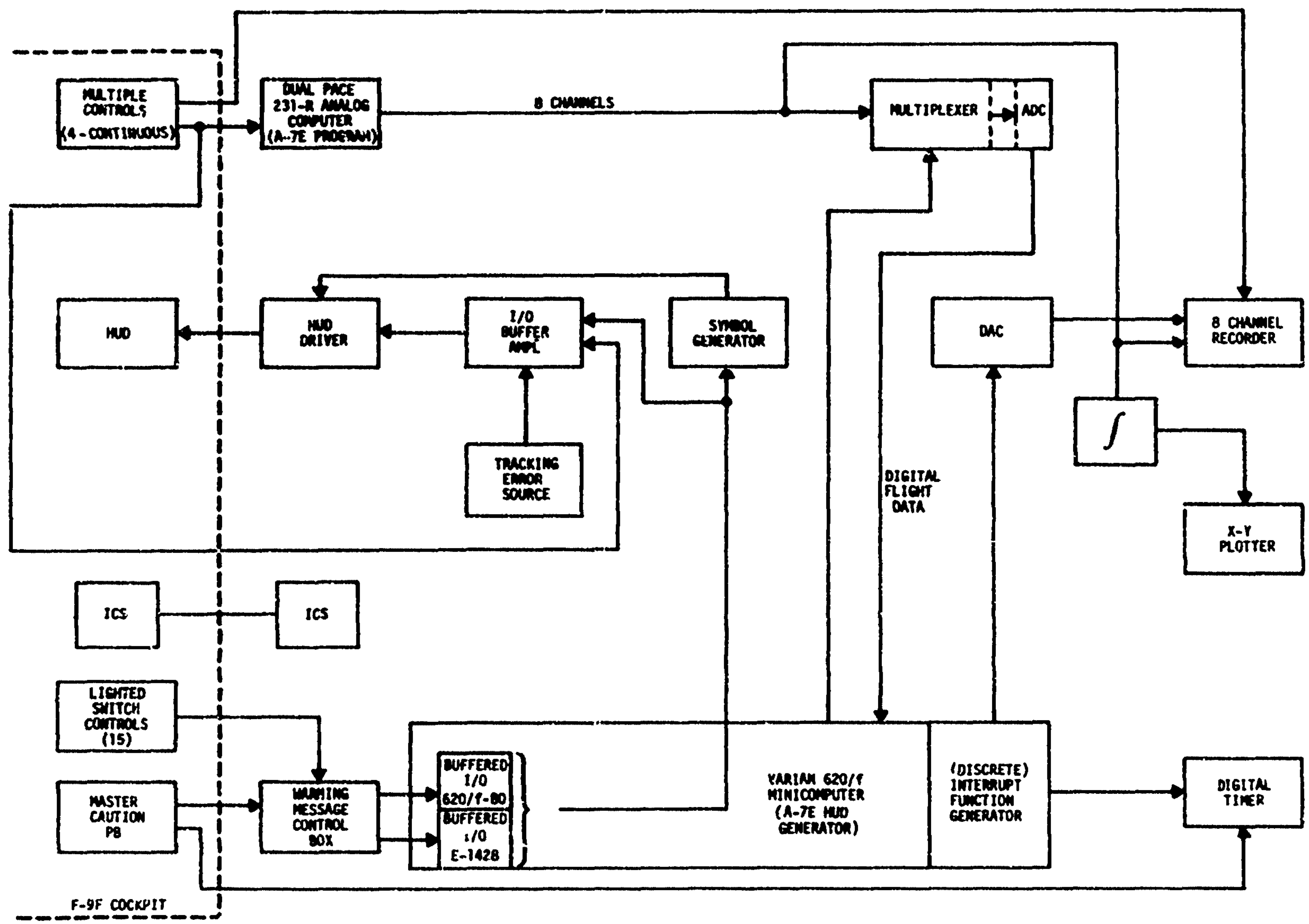


Figure 5-1. Simulator Block Diagram

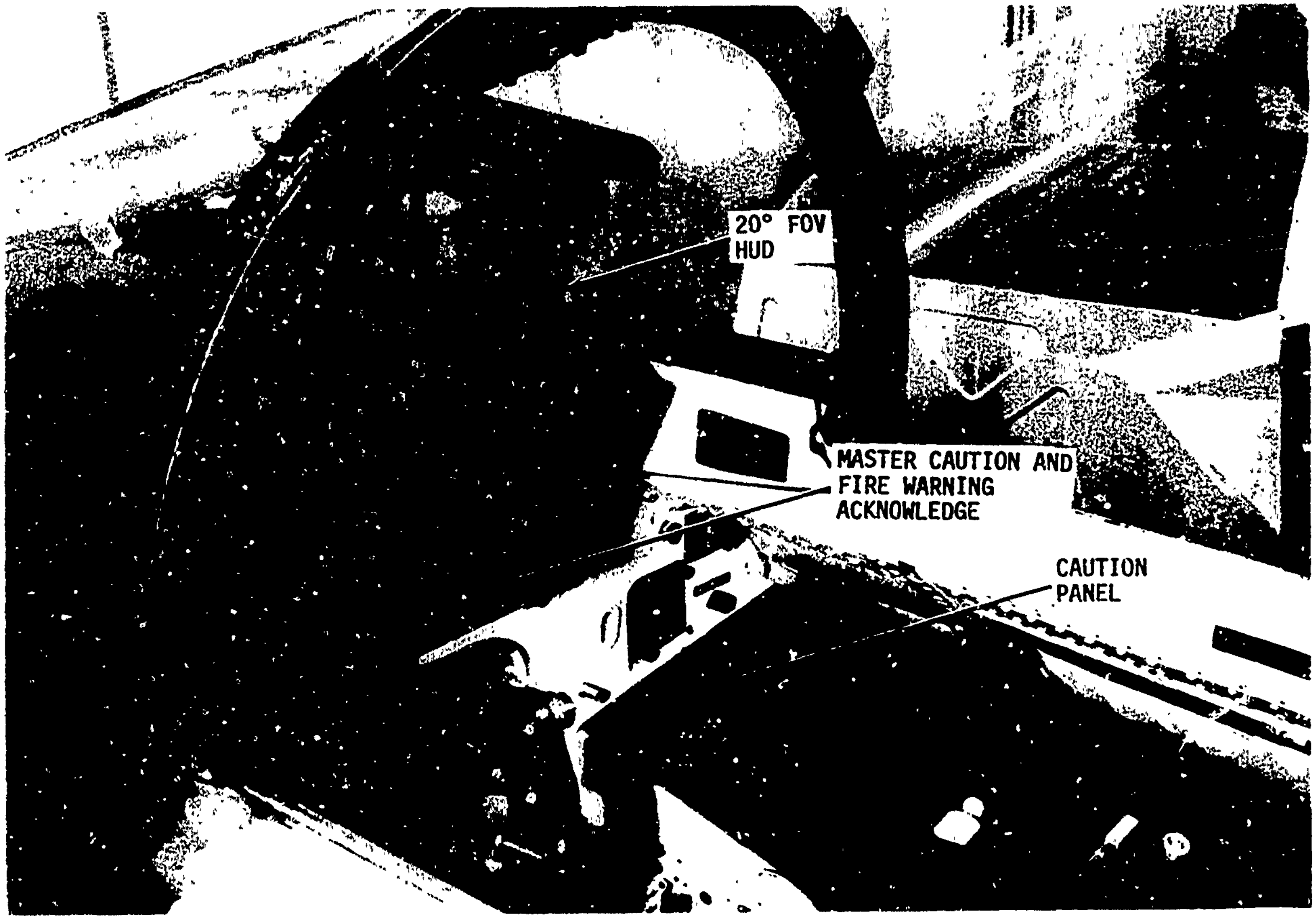


Figure 5-2. F-9F Cockpit

Figure 5-3. HUD System Simulation Laboratory

Preparing the aircraft simulation involved several steps. First, the equations and appropriate coefficients were determined. These describing functions were modeled for a fast time digital simulation using the GPSS-Norden language. The simulation was run on an IBM-370 to obtain parameter values and time histories of model performance. These two steps were performed initially using the simplified equations and coefficients of the F-4 aircraft, and subsequently using the equations and coefficients of the A-7E aircraft. Simulation data were obtained from LTV and NWC. A substantiation of our selected equations, terms, transformations, and coefficients was not available from the literature, but performance of the digital model of the A-7E, after debugging, was well behaved and realistic. With this confidence factor, we proceeded to develop an analog model and associated patch diagram for the PACE computer. This hybrid model was converted to a digital program and run in fast time to check the diagrams, scaling, performance, and stability against results from the digital aircraft simulation. The PACE 231R was then programmed and debugged. When completed, performance of the analog model was checked against time histories generated by the digital model for specific control exercises. There was good agreement between the dynamics of the two models. A detailed description of the various simulation programs has been separately provided to ONR.

The original plan was to test and validate the various message formats using this simulation and a programmable HUD display. The experiment was to involve a subject population of at least six Navy pilots with current A-7E flying experience. However, the Varian computer, which is one of the first production models, was not performing to the Varian specification at the date scheduled for contract completion. The computer supplier has now corrected this situation. Once the display program is debugged, a demonstration of the proposed HUD warning system will be offered to ONR and interested government personnel. Performance data will be taken during at least one demonstration and supplied to ONR as an addendum to this report.

During the demonstration, the pilot subjects will be exercised in one of the following ways. Two dimensional command, error, or turbulence data can be introduced to one of two preselected display symbols from a preprogrammed tape recording. In addition to voice commands to create pilot tasks, the experimenter can lead the pilot by means of a command symbol, driven by a 2-axis pencil controller that is part of the experimenter's control box. This control will move either the target designate symbol or the flight director command bars, at the experimenter's option. The experimenter is provided situational feedback by means of a separate display monitor. At random intervals, the

experimenter will introduce individual warning messages. The pilot will be presented with these warnings using either the traditional or the proposed method, thus permitting a comparitive evaluation of the two warning systems.

SECTION 6
SUMMARY, RECOMMENDATIONS, AND CONCLUSIONS

This study was performed to establish design requirements for future HUD warning systems. The following were the primary areas investigated:

a. rules for selecting warning signals

b. warning signal priorities as a function of mission phase

c. symbolic vs. worded messages

d. the value and acceptability of warning enhancement schemes, such as blinking, brightening, and color

e. the best size and location for warning messages

f. areas of the pilot's visual field to be avoided

g. the effectiveness of warning displays over the representative range of pilot workloads and typical mission operations

h. the use of auditory warnings

i. the use of emergency procedures displayed on the HUD

Norden's recommendations for HUD warning systems are summarized in Table 6-1. Preferred locations for HUD warnings are illustrated in Figure 4-12. Other accomplishments of this study are itemized in Table 6-2. The following paragraphs contain further discussions of specific topics.

6.1 The Overall Warning System; Auditory Warnings

For aircraft equipped with head-up displays, warning signals are best presented as blinking worded messages, accompanied by an auditory master alerting signal. (Refer to item i on page 2-7.) In addition, summary status at a glance is retained as with the standard, lighted legend caution/warning panel. A one-to-one correspondence is preserved between the

Table 6-1. Summary of Recommended HUD Warnings

①	MESSAGES AND PRIORITIES BY MISSION PHASE AS INDICATED BY NAS, CECIL FIELD AND NAS, LEMOORE (TABLES 3-2 AND 3-3)*
②	A SIMPLE BUT UNIQUE VISUAL MESSAGE, PARALLELED WITH AUDIO ALERT (REFER TO ITEM i ON PAGE 2-7)
③	CHARACTER HEIGHT OF ONE DEGREE VISUAL ANGLE
④	SINGLE LINE MESSAGES POSITIONED ON EITHER HORIZONTAL OR VERTICAL AXIS OF DISPLAY
⑤	POSITIONED WITHIN EIGHT DEGREES OF CENTRAL CONE, AVOIDING CENTRAL THREE DEGREES. (SEE FIGURE 4-12 ON PAGE 4-21).
⑥	BLINK AT 3-5 HZ; EQUAL ON-OFF; EFFECTIVE BRIGHTNESS ONE TO THREE TIMES THAT OF OTHER HUD SYMBOLS

*FINAL SPECIFICATION IS SUBJECT TO NEGOTIATION WITH THE PRIME CONTRACTORS AND THE APPROVAL OF THE PROCURING ACTIVITY.

Table 6-2. Other Accomplishments

1	RECOMMENDATIONS FOR OTHER HUD IMPROVEMENTS (REFER TO SECTION 3.1, AND APPENDIXES A AND B ENTITLED "ADDITIONAL COMMENTS OF TEST PILOTS AT NATC PATUXENT RIVER" AND "PILOT SURVEY POESITIONNAIRE AND RESULTS OF SURVEY.")
2	AN OBJECTIVE APPROACH FOR DEVELOPING ADVANCED DISPLAY REQUIREMENTS
3	AN EFFICIENT APPARATUS FOR TESTING HUD PRESENTATIONS
4	A COMPUTER PROGRAM FOR 4-D ANALYSIS OF VARIANCE
5	TWO A-7E SIMULATIONS (DIGITAL & ANALOG)
6	A PROGRAMMABLE HUD
7	NEW AREAS FOR INVESTIGATION - BLINK & SUPERIMPOSITION - PERIPHERAL ATTENTION - VISUAL-AUDITORY-TACTILE SIGNAL INTEGRATION - NEW USES OF HUD FOR: NIGHT OPERATIONS TOTAL INSTRUMENT W/HOR SIT INFO UNUSUAL ATTITUDES RENDEZVOUS & DOCKING FORMATION FLT THREAT AVOIDANCE NAP OF EARTH NAV

nomenclature of the HUD warning messages and the legends on the caution/advisory panel. The auditory warning is silenced by pressing the traditional master caution, or master warning light; the HUD warning is also turned off by the pilot's acknowledgement. An individual message may be inhibited from the caution/warning panel.

The caution/advisory panel is still required because of the need for maximum warning system reliability. The caution/advisory panel provides the added benefits of summary status at a glance (e.g., a landing checklist) and clues to failure obtained from recognizable patterns of multiple warnings; the auditory and HUD channels do not present multiple warnings.

A master auditory warning is recommended because there is no certainty of obtaining the pilot's attention by visual means alone. The effectiveness of a warning system is markedly increased by auditory signals, whose alerting value is independent of where the pilot is looking. The value of an auditory warning is especially apparent during nap-of-the-earth operations where the pilot's concentration is intense, and his attention is rigidly and narrowly fixed outside the cockpit. In any mission phase, the auditory warning is valuable for fixing immediate attention on such critical items as threats and collision.

Significantly, the Army has adopted a voice warning system (AN/ASH-19) for its new helicopters. The system contains up to 40 individual messages and works in conjunction with conventional visual warnings. The Air Force also uses voice warning systems. Their rationale is to insure rapid crew attention and response during complex visual workloads. Also, there are long periods of cruise flight when the crew may be inattentive to visual displays.

6.2 Display of Emergency Procedures

It is not recommended that emergency procedures be displayed on the HUD. Pilot reaction to this suggestion was decidedly negative. Such displays were deemed an overkill. If the displays were triggered automatically, they would clutter and obstruct the display and present an unnecessary distraction. Even if manually selected, their display on the HUD was not considered appropriate. From an engineering viewpoint, the programming and symbol generation of emergency procedures on the HUD would not be justified for cost effectiveness.

The A-7E pilots showed some interest in providing complete emergency procedures on the Projected Map Cockpit Display system. Some procedures are already manually selectable on this display, and the cost of completing and updating these data should not be high. The displayed data could be manually selectable, or keyed automatically by specific warning signals.

6.3 Response to Peripheral Warnings; Limits on Experimental Findings

The study showed that an individual can control his attention to increase it in the periphery and decrease it in the central, or foveal area. The result is an apparent increase in visual awareness; i.e., by consciously controlling his attention, an individual can read messages of appropriate size and location using his peripheral vision. This conscious expanding of visual attention is likely to be an already acquired skill of experienced pilots and is related to lookout doctrine.

Subjects conducting a central 1.5°, two-dimensional tracking task could readily learn to look without moving their eyes, maintain tracking errors to within about one quarter of a degree, identify and report targets on the ground, and still maintain vigilance over a 17° field of view for random momentary flashes. Considerable fatigue was reported after one-half hour of this behaviour, although good performance was maintained by all individuals. With practice, performance would improve and might be maintained for up to one or two hours in a given 24-hour period - but with decreasing confidence. If it had been practical to place subjects under high psychological stress, performance would undoubtedly have been altered, including reductions in peripheral visual attention (refer to Bursill), and fatigue would likely have increased.

The display format experiment, however, was performed only to determine the optimum display format parameters. In actual practice, HUD warnings would occur much less frequently than in the experiment and would remain illuminated until acknowledged. By comparison with actual practice, the experiment tended to increase vigilance and resulting fatigue, but was conducted in the absence of psychological stress. No conclusions on operational pilot response to warnings can therefore be made. Relative performance and pilot acceptance of the proposed and current warning systems may be established, however, by the evaluation described in Section 5 and by subsequent operational evaluation of a prototype programmable HUD.

6.4 Refining and Extending the Display Format Experiment

Optimum blinking characteristics were not determined by this study, and an experiment could profitably be performed to investigate blink rate and duty cycle for various symbols, symbol sizes, brightnesses, and symbol locations. The intention would be to use blinking to optimize both attention-getting and information transfer and to minimize obstruction of the external view.

A broader range of brightness, contrast, size, and location is recommended in any further experiments. Night operation of the HUD should also be investigated, with at least four levels of brightness used for both daylight and night time conditions. Particular care should be taken in selecting messages, their size, and their location to better control both the size-by-location interaction and the message factors, such as familiarity. The significance of the measured performance parameters deser[illegible] further study. Sufficient sensitivity, stability, and [illegible]ancy are very difficult to achieve, and a greater use of preliminary tests is advised.

6.5 Recommendations for Additional Research

Head-Up display usage is being extended across all mission operations and environmental conditions. The pilot survey has indicated potential difficulty in use of HUD at night. The HUD warning requirements developed in this study have not been optimized for use under low light level conditions. It is recommended that research be conducted to optimize the HUD warning message presentation for night flying conditions.

The need to establish integrated warning system requirements and to reduce pilot visual work load leads to a recommendation for research to determine warning system requirements and standards for the auditory and tactile senses in concert with vision.

The unique programmable HUD and aircraft simulation developed during this study offers a valid, rapid, and low cost method to evaluate new HUD symbols as well as symbols presently specified in MIL-D-81641. Of particular importance would be the evaluation of new symbols to reduce display clutter for night operations, to improve pilot reaction for threat avoidance, to provide way-point anticipation during low level flight, and to provide a more usable display of extreme pitch attitudes.

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d. F-15 HUD Specification, MDAC
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APPENDIX A
ADDITIONAL COMMENTS OF TEST PILOTS AT NATC, PATUXENT RIVER

Although the A-7E cockpit is very well human engineered, cockpit workload is still too high; simplification is considered necessary.

In attack and landing, cockpit procedure is tied to revolutions of the barometric altimeter as it unwinds. This is done via peripheral vision. Level of concentration on task is an important variable affecting scope of pilot's attention and vision. Pilot gets aircraft systems ready as early as possible prior to entering hostile area.

To further minimize obstruction to external vision, symbol color might be changed to yellow, a one mil stroke width used, and brightness reduced such that details of outside world would be seen through the symbols.

Do not wish to interpret symbols. Adds extra step. Favor messages over symbols because interpretation is not necessary.

Add CMPTR and TACAN bearing and range information on HUD.

If not in AIR TO GROUND ranging mode, then PULL UP warning symbol will never come on. Therefore an AGR OFF mode indication is desired, so that we'll at least know a PULL UP warning is not available.

General need for rapid, low cost software update capability for HUD and PMDS.

Suggest that alerting signal blink entire presentation.

Would like cheap airborne video recorder for immediate post attack analysis. Film processing delays feedback too long (up to 1 to 2 weeks)

Would like LOW ALTITUDE LIMITS on HUD. Use a different value for each:

LDG 200 feet

CRUISE 3000 feet

T/O -50 to 75 feet and 1000 feet were both suggested

The A-7 has difficult stall characteristics. Could use A0A command during combat maneuvering. Would not want A0A information as messages.

HUD A0A symbol should be fly-to, like all other cockpit director information.

Would like continuous A0A indexing for immediate trend information.

Would rather see digital readouts for altitude and airspeed. The Harrier aircraft HUD has this.

During automatic carrier landing, most discretes are (cryptically)* displayed on the HUD. Exceptions are COMMAND CONTROL, A0A OFF, COUPLER OFF. Suggest A0A OFF and COUPLER OFF be displayed as messages on HUD.

When SAMs are being fired continuously, for periods up to 15 minutes, the warble tone warning begins to drive you crazy, so you turn the warning volume off.

Would like an emergency proc[illegible] message at pilots' option; i.e., if you don't know what [illegible], you can ask the system (1).

A report on carrier suitability by Gary Beck suggests navigation information on HUD.

(It was reported that some threats could be identified and threat sequences could sometimes be followed via radio-ICS. This effect was not designed into ECM equipment, but seems to be a fruitful area to explore. Display of this type of information should be optimized across the pilot's visual-auditory and tactual sense modalities to fit the mission, aircraft, system, and psychological requirements.)

*Comments in brackets are the investigators.

APPENDIX B
PILOT SURVEY QUESTIONNAIRE AND RESULTS OF SURVEY

The following pages contain the questionnaire submitted to pilots at NAS, Cecil Field and NAS, Lemoore. Summary of pilot responses and comments have been entered in italics. Answers to Section III of the questionnaire have been summarized in Tables 3-2 and 3-3 of this report. Where numeric responses were solicited, the average response is given first, followed by the range in parentheses. For open-ended (exploratory) questionnaire items, response redundancy has been largely removed to aid the reader.

HUD CAUTION/WARNING SURVEY

As a preliminary step in an Office of Naval Research sponsored study of techniques for the presentation of warning information on head up displays, we are carrying out a survey of pilots with operational experience in the A-7. The results of this study will be used to develop criteria for warning systems in attack aircraft 10-15 years in the future and not to look for specific problems in the A-7. However, as A-7 pilots you have had operational experience with a HUD and with the first generation of HUD caution/warning techniques.

Among the questions which this program is intended to answer are:

- Is it desireable to place caution/warning messages on HUD?
- Should the messages and priorities be the same for each flight phase?
- Should the messages be general or specific?
- What display methods are best for these messages?

The questionnaire is in three sections. The first covers general questions relating to all phasesof the mission; the second covers each phase in some detail; and the third section involves the specific messages which can occur in each phase. Please base your answers specifically on your A-7 experience.

Your responses to this survey will be compiled with others and used as statistical background information to guide us in planning the remainder of the study. We will talk to some of you further to follow up your comments. Be assured, however, that your names will not appear with your responses in any of our reports.

We would like to thank you in advance for your cooperation in this survey.

HUD CAUTION/WARNING SURVEY

NAME_______________ RANK_______________ SQUADRON_______________

DATE DESIGNATED AVIATOR _______________ TOTAL HR _______________
Month Year

PRESENT ASSIGNMENT _______________

		HOURS
ESTIMATED HOURS	A-7 ALL MODELS	____
ESTIMATED HOURS	A-7A OR A-7B	____
ESTIMATED HOURS A-7D OR A-7E		____
with OPERATING HUD		____
OTHER AIRCRAFT with HUD		____
TYPE _______________		____
TYPE _______________		____

SECTION I GENERAL

1. What is your opinion of the present master caution/warning symbol on the HUD?

  - 32 Excellent
  - 38 Good
  - 16 Adequate
  - 3 Needs Improvement
  - ____ No Value
  - ____ Impairs Operation or Safety or Both

2. When viewing the world ahead through the HUD do you ever feel that the symbols interfere with your view?

  Daylight: 37 Yes
  52 No

  Night: 63 Yes
  24 No

  If yes in either case, describe ____

  Refer to page B-5.

SECTION I GENERAL

Question No. 2

Lines too broad. Scales interfere with outside view, especially at night. Can't dim symbology down sufficiently at night. Notice a forced transition from symbols to outside view. Can't concentrate on target scan or target if acquired.

In daylight, occasional interference from scales. At night, definite problem with scales; sometimes have to turn HUD off entirely to see lights ahead on another A/C.

Although focused at infinity, symbols still tend to distract from lookout doctrine in daylight. Night time symbols cut down contrast.

I fly at least 90 percent with scales off because they interfere with view.

Too bright at night. Don't use in mirror approach because presentation causes eyes to focus on HUD symbols instead of meatball and lineup.

Normally fly with scales off.

Lines too wide, especially at night.

Intensity too hard to adjust.

Difficult to concentrate beyond symbols when not too much to see.

3. Do you feel that the HUD has any influence on your ability to avoid collisions?

Daylight: 15 Collisions more likely

27 Collisions less likely

43 No Effect

Night: 29 Collisions more likely

21 Collisions less likely

35 No effect

Comments: *Refer to page B-7.*

4. Do you ever feel that the HUD symbols are not in focus when you are viewing the area ahead of the aircraft?

75 In focus

11 Not in focus

Comments: *Refer to page B-7.*

SECTION I GENERAL

Question No. 3

Hard to look thru HUD symbols.

Hard to find lighted objects at night.

FPM good for low level air routes. Gives instant, accurate evaluation of air routes.

Combining glass reduces forward vision somewhat.

Good for avoiding air-to-air collisions - not so good for avoiding ground collisions.

In closing situations can more quickly and accurately decide whether to climb or dive due to exact horizon and FPM.

In VMC you tend to look straight ahead instead of scanning entire sky.

Night acquisition of other A/C at 12 o'clock is more difficult.

HUD good at night for keeping head out of cockpit. A/C easier to spot at night.

Good in low level. Harder to initially detect A/C. FPM helps avoid A/C. Need training to look thru symbols. Symbols same color as formation lights.

Question No. 4

Transition from HUD symbols to outside world and back must be learned and is an effort. Also, symbol interpretation takes time away from scan.

Ninety-nine percent in focus; bad focus sometimes due to bad gear.

After concentrating on symbols for a period, with no ground to look at, you develop HUD "myopia". You don't see bits of ground or other aircraft when they appear.

5. Is there ever a time in a mission when workload is so high that you would not immediately look at the caution panel to determine the cause of a master caution/warning message.

_48_ Yes

_40_ No

What circumstances? How long would you delay? ______

Refer to page B-9.

6. While looking through the HUD and a caution/warning message occurs where do you get your first cue?

_23_ Always the HUD warning symbol

_31_ Usually the HUD warning symbol

_19_ 50 - 50 HUD or panel

_12_ Usually panel master caution light

_1_ Always panel master caution light

_1_ Other *Weapon Delivery 100% HUD*
All other cases 50/50 HUD or Panel

SECTION I GENERAL

Question No. 5

Pull out from bombing run, 1-2 sec.

IFR formation, 3 minutes max

In Flt. refuel, 3 minutes max

Catapult take off, 5 to 10 seconds

Carrier landing, 10-15 seconds

MIG/SAM BREAK

JINKING PULLOFF

Any critical A/C maneuver until recovery initiated.

Night RDZ

In close carrier pass, 5 seconds

When under positive control and given several instructions - 5 sec.

Night carrier landing, delay until comfortable.

Night catapult shot

Dive bomb run (near completion). Delay until release.

Intermittent false HUD failures cause me to disregard the Master Caution, and therefore delay catching an actual problem.

Delay in dive bomb until nose approaching horizon, 3-10 sec.

T-O, cat shot until safely airborne.

R/V when looking for and lining up with wingman.

3-4 sec just prior weapon release.

Last 1/2 mile of carrier landing (@ 135 mph = 5.6 sec).

7. When looking inside the cockpit where do you get your first cue to the occurrence of a caution/warning message?

1 Always the HUD warning symbol

5 Usually the HUD warning symbol

5 50 - 50 HUD or panel

43 Usually the panel master caution light

31 Always panel master caution light

2 Other *Lite on Caution panel itself. Gauges on Instrument Panel - can't see panel MC.*

8. When looking outside the cockpit to either side, where do you get your first cue to a master caution/warning signal?

1 Always the HUD warning symbol

9 Usually the HUD warning symbol

24 50 - 50 HUD or panel

48 Usually the panel master caution light

10 Always the panel master caution light

1 Other *Individual panel Caution light*

9. Can you think of a circumstance where you or someone you've heard about has missed a caution/warning indication for a period of time you consider to be too long?

14 Yes

73 No

Describe circumstances *Refer to page B-11*

SECTION I GENERAL

Question No. 9

Cockpit lites left on at dawn (caution lites are dimmed); caution washed out by direct sunlight.

Tall pilot missed LAUNCH BAR LT; no HUD indication.

5-6 minutes ECM engagement.

With seat full up, can't see Master Caution light.

With HUD, no delay 99 percent of time. Without HUD I might miss a panel light for a long time.

With HUD inoperative and bright sun during landing approach, can't see panel Master Caution.

With normal seat, the view of panel Master Caution light is blocked.

During combat maneuvering, with seat high, the panel Master Caution is blocked.

At night, with symbols dim and during formation flight.

10. Can you think of a circumstance where the caution/warning symbol on the HUD has interferred with the operation needlessly?

20 yes

67 no

Describe Situation *Refer to page B-13*

11. How would you feel about a HUD warning system which places words in your field of view to describe the system fault?

31 Would help

20 Would make no difference

33 Would interfere with task

3 Don't Know

12. In which mission phase would such a technique (words on HUD) be of the most benefit?

31 Takeoff

12 Cruise/NAV

30 Attack

28 Landing

1 Formation

1 Useless

3 None

13. How would you feel about voice messages for the presentation of warning/caution information? *(not formally presented at Cecil Field)*

10 Would help

7 Would make no difference

23 Would interfere with tasks

9 Don't know

SECTION I GENERAL

Question No. 10

Intermittent low fuel level; I must constantly punch off the Master Caution light on Mode II Night Carrier approach.

No problem because can turn it off quickly.

HUD Fail illuminates without apparent failure. Only apparent failures of HUD have been frozen presentation or lack of picture. These failures were not signalled.

If you are to take a deep breath on cat shot, temperary O_2 and caution lights come on immediately after cat shot.

Terrain following

Intermittent or erroneous warnings.

During cat shots, - a look at caution panel might prove fatal. Only reason it hasn't is MC light comes on 40-60% of time for O_2 (everyone knows it and doesn't look).

O_2 in take-off

Fuel in landing.

Intermittents (Master caution on, but no item in cockpit panel on by the time you look at it.)

14. As an alternative to words on the HUD would you prefer symbols representing each caution/warning message?

6 Yes

81 No

15. The present HUD master caution/warning symbol consists of 6 stationary slanted lines. In order to speed the pilot's detection of the caution/warning message the following techniques have been suggested. Rank them in order of preference.

6 Moving presentation

1 Flashing presentation

5 Color presentation

4 Larger area presentation

3 Present Master Warning symbol

7 Peripheral presentation

2 Auditory signal

16. It has been suggested that response statements telling you how to deal with a specific warning/caution condition could be presented via the HUD. Assuming that these messages were maintained up to date, what is your reaction?

18 Good Idea

37 Possibly useful

30 Poor Idea

2 Don't know

17. Is there any additional information that could be presented via HUD to make your job easier or more effective? Please comment. *Refer to page B-15.*

SECTION I GENERAL

Question No. 17

HUD too cluttered now.

Display range and bearing to or from selected destination, or TACAN

Don't use scales now, therefore cannot imagine more.

Provide digital readout of altitude and airspeed.

In normal attack mode, need to know whether using AGR, BARO or RAD altitude.

Need ranges and distance to destination.

Better (decluttered) airspeed and altitude presentations.

TACAN info; during gear down phase, want sliding power scale (75%-100%) across top. (at HUD, thermometer type)

Cage aiming reticle at high drift angles.

Would like display simplified.

TAS/IAS readout

Include flashing warning when exceeding Radar Alt low alt limit

Want smaller (1 mil) aiming reticle.

A different altitude scale at heights below 1000 ft. would be useful on IFR approach.

I like the idea of displaying words identifying system failure rather than just lines.

Digital airspeed, altitude; scale for g.

Smaller aiming diamond.

Red Master Warning symbol

Radar aiming symbol.

Present system OK except for cluttering at high drift angles. Need larger field of view to see all symbols without moving head.

SECTION II MISSION PHASES

A. TAKEOFF PHASE

The takeoff phase is defined as the period between engine start and clean aircraft configurations.

1. During takeoff do you use the HUD

	YES	NO	SOMETIMES
At all?	40	14	29
Daylight?	38	18	33
Night?	35	24	22
Carrier?	25	29	17
Field?	35	14	32

2. What percentage of time do you use the HUD from beginning of takeoff roll to clean configuration?

   40 (0-100) %

3. What warning/caution message would you expect to occur most often during takeoff?

   Refer to page B-17

4. How many caution/warning messages would you expect in 1000 takeoffs?

   5 (0-100)

SECTION II MISSION PHASES

A. Question No. 3

HUD Fail

Engine Hot

Launch Bar

O_2

Fire

Engine Oil Pressure

Platform

HUD Hot

Gear/Flaps

Hydraulic Pressure

Fuel Pump

AFCS

Flame-out

5. What is the longest period you would spend "locked on" the HUD (no cockpit scan) during takeoff?

3 (0-30) seconds

6. Below is a square representing the visual field of the HUD. For the takeoff phase where would you place caution/warning information?

1	2	3
4	5	6
7	8	9

First Preference 8

Second Preference 2

10 not on HUD

B. <u>CRUISE - NAVIGATION PHASE</u>

This phase is defined as the period with clean configuration prior t selection of an attack mode on the function panel.

1. During the cruise phase do you use the HUD

	YES	NO	SOMETIMES
At all?	80	1	8
Daylight?	69	0	17
Night?	63	4	19
IFR?	53	6	30
VFR?	54	0	20

2. What percentage of time do you use the HUD during this phase?

IFR 50(0-100) %

VFR 50(5-100) %

3. What caution/warning message would you expect to occur most frequently during the cruise phase?

Refer to page B-20

4. How often would you expect to have a caution/warning message occur during the cruise phase?

25

One every *(1-1000)* hours.

5. What is the longest period you would spend "locked on" the HUD (no cockpit scan) during the cruise phase?

15(0-120) seconds.

6. The square below represents the visual field of the HUD. Where would you place caution/warning information?

1	2	3
4	5	6
7	8	9

10 not on HUD

First preference *8*

Second preference *2*

SECTION II MISSION PHASES

B. Question No. 3

Oil Pressure

Engine Hot

AFCS Pitch

HUD Fail

Hydraulic Pressure

Fuel Low

Fuel Boost

O_2

INS Not Aligned

Speedbrake

Doppler

Computer

Platform

HUD Hot

7. Do you use the HUD as the primary display for IFR flight?

Daylight 22 Yes

65 No

Night 19 Yes

67 No

If no in either case, what changes in the display would allow you to use the HUD as a primary IFR display?

Refer to page B-22

C. ATTACK PHASE

The attack phase is defined by the selection of an attack mode on the master function selector panel.

1. What percentage of time during the attack phase is the HUD being used?

80(10-100) %

2. What caution/warning message occurs most often during the attack phase?

Refer to page B-23

3. How often would you expect to have a caution/warning message occur during the attack phase?

One every 100 (1-1000) hours.

SECTION II MISSION PHASES

B. Question No. 7

Small bank angles hard to detect; hard to keep wings level.

Don't think I (an old buck) could change my patterns and habits enough to rely on it primarily.

Change pilot technique.

Requires more experience.

Use HUD for HDG and attitude

Prefer cockpit A/S & Alt.

Never; very little to see outside if IFR

Need better differentiation between nose up and nose down attitude; unusual altitudes almost impossible, whereas with ADI it's easy.

Habit and preference keep me from using it as primary.

Limit lateral movement of FPM and pitch lines.

Need wider field of view to see all symbols without moving head.

Why use HUD in IFR? You're just looking at clouds and darkness anyway.

Make it more like ADI. Bigger FPM to get better angle of bank.

Change AOA bracket to be consistent with approach indexes.

More accurate altitude, easier to read ROC. Longer wings on FPM.

I'm too old to change.

Finer lines

Better attitude reference, larger airplane symbol.

Induces vertigo when IFR.

ADI easier to interpret, easier to view; have had much more training on this, greater confidence.

Easier to read A/S, Alt, and ROC are needed on HUD

More reliable AOA.

SESSION II MISSION PHASE

C. Question No. 2

Engine Oil

Engine Hot

HUD Fail

Computer

Platform

AFCS Pitch

AFCS Roll

Fire

Hydraulic Pressure

Doppler

O_2

Pullup

Fuel Pump

4. What is the longest period during the attack phase where you are "locked on" to the HUD (no cockpit scan)?

10(0-60) seconds

5. The square below represents the visual field of the HUD. Where would you place caution/warning information on the HUD during the attack phase?

1	2	3
4	5	6
7	8	9

First preference 8

Second preference 2

10 Not on HUD

6. Where would you like to have the ECM messages displayed?

As they are now 64

On the HUD 4

On the panel and HUD 15

Other 0

Don't know 1

D. <u>LANDING PHASE</u>

The landing phase is initiated by extension of gear or flaps and is terminated with weight on the wheels.

1. Do you use the HUD for landing

	YES	NO	SOMETIMES
At all?	54	3	29
Daylight?	44	4	40
Night?	37	18	29
VFR?	45	[illegible]	44
IFR?	30	24	31
Carrier?	25	26	22
Field?	46	4	31

2. What percentage of time do you use the HUD for the following types of landings?

VFR 65 (0-100) %

GCA 65 (0-100) %

ACLS 40 (0-100) %

3. What caution/warning message occurs most often in the landing phase?

Refer to page B-26

4. How many caution/warning signals would you expect in 1000 landings?

15 (1-300)

SECTION II MISSION PHASE

D. Question No. 3

Rain Remove Hot

O_2

Low Fuel

Anti-Skid

Doppler

Hydraulic Pressure

Gear/Flaps

HUD Fail

5. What is the longest period you would spend "locked on" the HUD (no cockpit scan) during landing?

5(0-300) seconds

6. The square below represents the HUD field of view. Select the location where you would place caution warning information for the landing phase.

1	2	3
4	5	6
7	8	9

10 Not on HUD

First preference *8*

econd preference *5*

7. Comparing instrument approaches made with and without the HUD, which allows earlier acquisition of approach lights?

48 earlier with HUD

8 later with HUD

23 no difference

1 don't know

SECTION III. CANDIDATE MESSAGES

The lists presented in this section summarize potential caution/warning messages for each flight phase. We would like your ideas on which messages should be presented on the HUD. First, we would like you to go through each list and decide which messages should activate a caution/warning message on the HUD. Place a check in the column labeled "HUD Caution/Warning" along side of each message you select.

Next, consider each of the messages which you have selected and decide which you would like to see displayed as specific messages on the HUD. For example, you might decide that the word "FIRE" should appear on the HUD along with a master caution/warning message. To indicate this place a check in the column labeled "SPECIFIC MESSAGE" along side of the word "FIRE".

As a final step we would like you to look at the messages where you have checked the "SPECIFIC MESSAGE" column and rank them in order of priority. This ranking will assist in deciding which message to present first if two problems occur at the same time. Start with the number one for the highest priority message.

Raw data in this section has been omitted. Range and relative frequencies of responses were developed and used to determine the message lists in order of priority by mission phase. These message lists appear as Tables 2-2 and 2-3.

A. TAKEOFF PHASE

HUD CAUTION/ WARNING	SPECIFIC MESSAGE	RANK	CANDIDATE MESSAGES
			FIRE
			WHEELS/FLAPS
			LAUNCH BAR
			MASTER CAUTION
			TILT
			ENGINE OIL
			OXYGEN
			PLATFORM
			COMPUTER
			ENGINE HOT
			HYDRAULIC PRESSURE
			MAIN FUEL PUMP
			ANTI-SKID
			RADAR ALT. OFF
			MASTER GEN FLAG

B. CRUISE/NAVIGATION PHASE

HUD CAUTION/ WARNING	SPECIFIC MESSAGE	RANK	CANDIDATE MESSAGES
			FIRE
			MASTER CAUTION
			TILT
			ENGINE OIL
			OXYGEN
			PLATFORM
			FUEL LOW
			RAIN REMOVE HOT
			COMPUTER
			ENGINE HOT
			HYDRAULIC PRESSURE
			MAIN FUEL PUMP
			FUEL BOOST
			HUD HOT
			WING PRESSURE
			IFF
			OIL QUANTITY
			PMDS FAIL
			ANGLE OF ATTACK OFF
			DATA LINK
			ARM
			ORBIT

CRUISE/NAVIGATION PHASE (CONT'D)

HUD CAUTION/ WARNING	SPECIFIC MESSAGES	RANK	CANDIDATE MESSAGES
			ABORT
			FREE LANCE
			MAG VAR
			LATITUDE
			IFF
			ALTITUDE LOW
			IN RANGE
			ECM INOP
			ECM REC
			ECM RPT
			PC-1, 2 or 3 LOW
			LORAN SEARCH
			LORAN UNRELIABLE
			ECM TEST
			MASTER ARM
			IR COOL
			MASTER GENERATOR FLAG
			RADAR FAIL

C. ATTACK PHASE

HUD CAUTION/ WARNING	SPECIFIC MESSAGE	RANK	CANDIDATE MESSAGE
			FIRE
			WHEELS/FLAPS
			LAUNCH BAR
			MASTER CAUTION
			TILT
			ENGINE OIL
			OXYGEN
			PLATFORM
			FUEL LOW
			COMPUTER
			ENGINE HOT
			HYDRAULIC PRESSURE
			MAIN FUEL PUMP
			FUEL BOOST 1 or 2
			EMERGENCY HYDRAULIC ISOLATION
			HUD HOT
			MANUAL FUEL CONTROL
			WING PRESSURE
			AIR DATA COMPUTER
			IFF
			OIL QUANTITY FLAG
			WEAPONS SAFE
			RADAR ALTITUDE OFF

ATTACK PHASE (CONT'D)

HUD CAUTION/ WARNING	SPECIFIC MESSAGE	RANK	CANDIDATE MESSAGE
			LAUNCH ALERT
			AI W AI DAY
			SAM H1
			SAM 3 (X)
			SAM 2 (SRC)
			SH1
			SLO
			CHL
			X-HL
			X-LO
			AIW
			A1 DAY
			LORO
			AAA
			PC-1, 2 or 3 LOW
			COMMAND CONTROL
			NO MSG
			ARM
			ORBIT
			DROP
			ABORT
			FREE LANCE
			ALTITUDE LOW
			IN RANGE
			ECM INOP
			ECM REC
			ECM RPT

ATTACK PHASE (CONT'D)

HUD CAUTION/ WARNING	SPECIFIC MESSAGE	RANK	CANDIDATE MESSAGE
			DATA LINK
			RADAR BOMB
			NORM ATTACK
			IF
			NAV. BOMB
			OFFSET
			TYPE WPN SELECTED AND ARMED
			ROUNDS REMAINING
			READY TO FIRE
			PULL UP
			NOSE FUSE
			TAIL FUSE
			MASTER ARM
			RATE OF FIRE HI OR LOW
			RETARDED WEAPON
			SMOKE
			CAMERA
			IR COOL
			POD CLEAR
			MASTER GENERATOR FLAG
			RADAR FAIL
			IN RANGE
			RADAR BEACON

ATTACK PHASE (CONT'D)

HUD CAUTION/ WARNING	SPECIFIC MESSAGE	RANK	CANDIDATE MESSAGE
			NO MESSAGE
			LDG GEAR IN TRANS
			ALTITUDE LOW
			DATA LINK
			MASTER GENERATOR

D. LANDING PHASE

HUD CAUTION/ WARNING	SPECIFIC MESSAGE	RANK	CANDIDATE MESSAGE
			FIRE
			WHEELS/FLAPS
			LAUNCH BAR
			MASTER CAUTION
			TILT
			PLATFORM
			FUEL REMAINING (MINUTES)
			COMPUTER
			ENGINE HOT
			HYDRAULIC PRESSURE
			MAIN FUEL PUMP
			FUEL BOOST 1 or 2
			AFCS
			WEAPON ARMED
			ANGLE OF ATTACK OFF
			APPROACH POWER COMP
			COUPLER OFF
			COMMAND CONTROL
			"10 SECOND"
			ACL READY
			LANDING CHECK

APPENDIX C
INSTRUCTIONS TO SUBJECTS PRIOR TO DISPLAY FORMAT EXPERIMENTS

We are performing a study for the Office of Naval Research which will affect the design of future head up displays. Specifically, we are studying methods of warning the pilot of dangerous conditions that have been detected either outside or inside his aircraft. These warnings must be presented such that he can respond rapidly, correctly, and with minimum interference with his primary tasks of flying and performing the mission. Examples of these dangerous conditions are:

a. A surface-to-air missle has been launched and is closing on his aircraft.

b. A fire has been detected in the engine.

c. A drop in hydraulic pressure has occurred which may affect his ability to control the aircraft.

d. Fuel quantity is low (only enough to get back to base).

e. The inertial system is malfunctioning such that automatic flight control and/or navigation systems are unreliable.

f. A computer failure has occurred.

In this experiment, you will observe a moving aerial scene similar to what a pilot might see while flying low at 300 knots. Superimposed on this scene are simulated HUD symbols. The central rectangular symbol will tend to move in various directions away from the central aircraft symbol. Your task is to track or follow this movement using the force joy stick such that you maintain the aircraft symbol centered in the box like this -⊡-. During the experiment, your errors in azimuth and altitude will be monitored and permanently recorded. After you have received sufficient practice on the tracking task, the tests of warning signals will begin. During these tests, you will hold the reaction bar with your left hand and depress the ready button on the end of this bar with your left thumb. At random intervals while you are tracking with your right hand, a warning message will appear momentarily in your field of view. You are to signal your response by releasing the reaction bar and depressing one of the three message push button using your left index finger. You are to respond as rapidly as possible. I will now demonstrate the procedure for you and then you may try it yourself. As you can see, we are changing the message, the message location, the

message size, and the message color in a random manner. Your reaction time to these messages are being measured in three ways: your initial reaction upon release of the ready button on the bar and your final reaction when you stop the clock by hitting the correct panel pushbutton. The third way is by checking your tracking performance. During the tests we may communicate via the intercomm. Pilot's duties also include avoiding collisions and identifying way points and targets of opportunity. Throughout the tests you should look for unusual objects and report them. For example:

a. highway crossing - now

b. dirt road - to right - no traffic

c. power plant - on left

d. river crossing - now

e. approaching city

f. departing city

g. highway on right - heavy traffic

I hope the helmet is comfortable. It is necessary to ensure the right apparent size of the presentation by fixing eye rotation. Please report image fuzziness or other effects which might interfere with your performance. Are there any questions?